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An Examination of the Impact of Moon Phase on Catch Rates of the Western Rock Lobster

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USE OF THESIS

An Examination of the Impact of Moon Phase on Catch Rates of the Western Rock Lobster

BY

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ABSTRACT

The western rock lobster is the most valuable single-species fishery in Australia returning a commercial value of around $250 million annually. This fishery is considered fully exploited and requires careful management to ensure a viable and sustainable fishery. Scientists at Marine Research Laboratory, Western Australia have already built detailed computer models of the lobster fishery and further research is required to continuously update and refine these models to provide an accurate picture of the fishery. One area of interest that could improve this model is the impact of the moon phase, if any, on the daily catch rates of the western rock lobster. The data sets used in this project aggregates of the daily catch separated into three major regions located off the western coast of Western Australia taken over several consecutive years. A number of time series methods such as classical decomposition and exponential smoothing were used to identify trend and cyclic components of the series. Indices for the lunar phase were calculated and compared for the detrended time series data corresponding to different depths and lobster phases at the three major regions. Comparisons were made between the various techniques, the years, zones and depths. Results showed a strong relationship between the full moon phase for some of the combinations of zones and depths while no conclusions could be drawn for the other moon phases. It is hoped that these results will further refine the catch rate models, which are important for management decisions to ensure the sustainability of the fishery.

DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

(i) incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution of higher education;

(ii) contain any material previously published or written by another person except where due reference is made in the text; or

(iii) contain any defamatory material.

Signature [redacted]

Date 9 · 3 · 00

ACKNOWLEDGMENTS

I would like to thank Fisheries Western Australia Research Division, Waterman for making the raw data (weight of catches and number of pots) for the western rock lobster available to ECU. I would also like to thank Nick Caputi and Norm Hall for making this project possible, and for their suggestions and encouragement.

Special thanks must go to my supervisor Associate Professor James Cross for his patience, tireless support and encouragement.

Thanks also to two special friends, Donna and Tara who always provided hope and laughter when the going got tough.

Most importantly I would like to thank my husband, Paul and my family who have also given me encouragement and without their support this project would not have been possible.

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1. INTRODUCTION

This section introduces some general background information on the Western Rock Lobster fishery including location, a brief history and the importance of research of the fishery.

1.1 Background and Significance

This project examines the possibility of a relationship between catch rates of the Western Rock Lobster and lunar phase. This information will provide further statistical data for stock assessment models. The results of stock assessment models are used both by fisheries to predict Western Rock Lobster numbers and fisheries managers to ensure that controls are adequate to protect breeding stocks and the sustainability of the fishery.

Lunar phase has long been used as a reference by fishermen to predict when the best fishing will take place. Research, such as that done by Neumann (1981), has shown that many coastal marine organisms have behavioural rhythms that coincide with changes in their environment. Decoursey (1983) found that moulting and reproduction in crustaceans coincided with semilunar and lunar cycles. Correlations have also been found between moonlight intensities and spatial distribution patterns in calanoid copepods. (Jerling & Wooldridge, 1992). However, these studies all refer to highly visible intertidal organisms or shallow estuary waters. There are fewer examples of neritic species, and fewer still for oceanic species. (Courtney, Die & McGilvray, 1996).

The Western Rock Lobster (WRL), Pannulirus Cygnus fishery is situated along the western coast of Western Australia and is subdivided into three major zones. These are the south coastal, north coastal and Abrolhos Islands. The western rock lobster is caught up to 60km off the coast between Augusta and Shark Bay.

The western rock lobster fishing industry is very important to the Australian economy returning the most export dollars for any single-species fishery in Australia. It has a commercial value of approximately $250 million annually to the fishers. (Fisheries Western Australia, 1998)

The industry catch has averaged 10 850 tonnes per year over the past 10 years. In the 1950 season the catch per unit effort (kg per pot lift) averaged around 1.645kg per pot while the 1997/98 season averaged around 0.94kg per pot. Figure 1.1 shows how the catch per unit of effort has declined from the late 1940's to the present date. Much research has been done to ensure that sustainable catch rates of the fishery are maintained. This is important both economically to guarantee commercial yields and biologically as there is concern that over-exploitation is endangering the fishery.

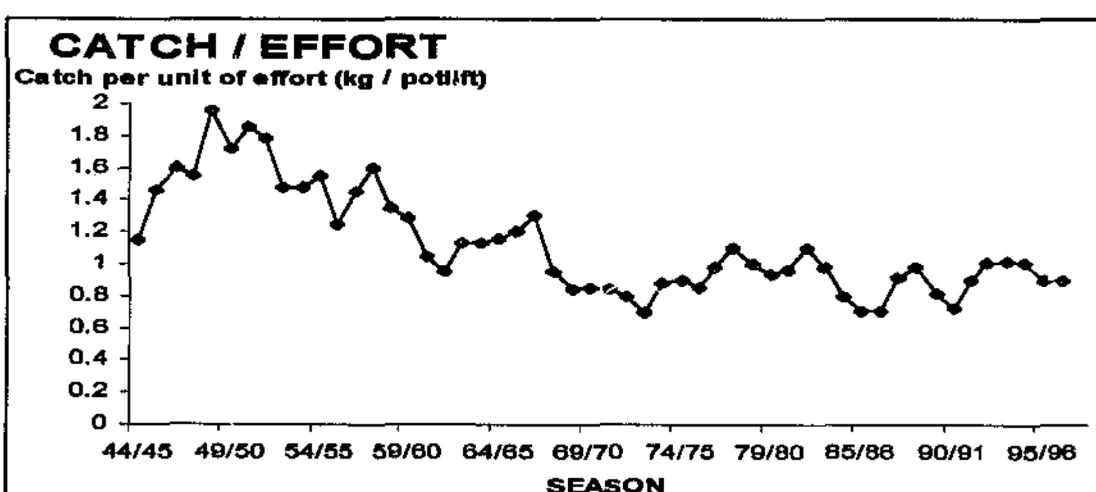


Figure 1.1 Time series of catch rate (kg per pot lift). (Fisheries Western Australia, 1999)

1.2 Importance of Research

The present study addresses the impact of moon phase on catch rates of the Western Rock Lobster. This research should provide further statistical information on the catch rates to enable an assessment of the stock status and thus ensure sustainability of the fishery. Scientists at Fisheries Western Australia have developed sophisticated models to estimate the abundance of the Western Rock Lobster. The mathematical models are continually being refined and tested to ensure that these models provide accurate and reliable information. Some of the factors which affect catch rates include fishing effort and environmental factors such as water temperature, swells, storms and tides. The impact of the moon phase on catch rates is an area where little research has been done. There has been some research into the impact of the moon phase in other fisheries. In Western Australia full moon closures are compulsory in the major prawn fisheries in Exmouth Gulf and Shark Bay. These closures reduce fishing when catch rates were believed to be lower and reduce fishing effort.

The status of the Western Rock Lobster is 'fully exploited' (Fisheries Western Australia, 1998). Good management strategies are required to maintain sustainable catch rates to ensure commercial yields and ensure that the fishery is not over-exploited which would be both biologically and economically undesirable. Abundance of populations are inferred from catch rates. Since management decisions are based on estimates of stock abundance, not only are catch and effort statistics important but other variables need to be taken into consideration to ensure that the models used to predict stock are accurate and reliable. It is already known that Puerulus settlement is affected by the strength of WA's Leeuwin Current and westerly wind conditions. The stronger the current and winter storms, the better the settlement (Caputi, Chubb & Brown, 1995a).

An understanding of the changes in catchability will provide improved estimates of indices for recruitment and stock assessment. To interpret catch rate data it is important to understand why and when catches are either greater or smaller. To help improve stock assessment models we need to know which factors have a significant role and which are arbitrary. Therefore we want to know whether the moon cycle impacts on the Western Rock Lobster catch rates.

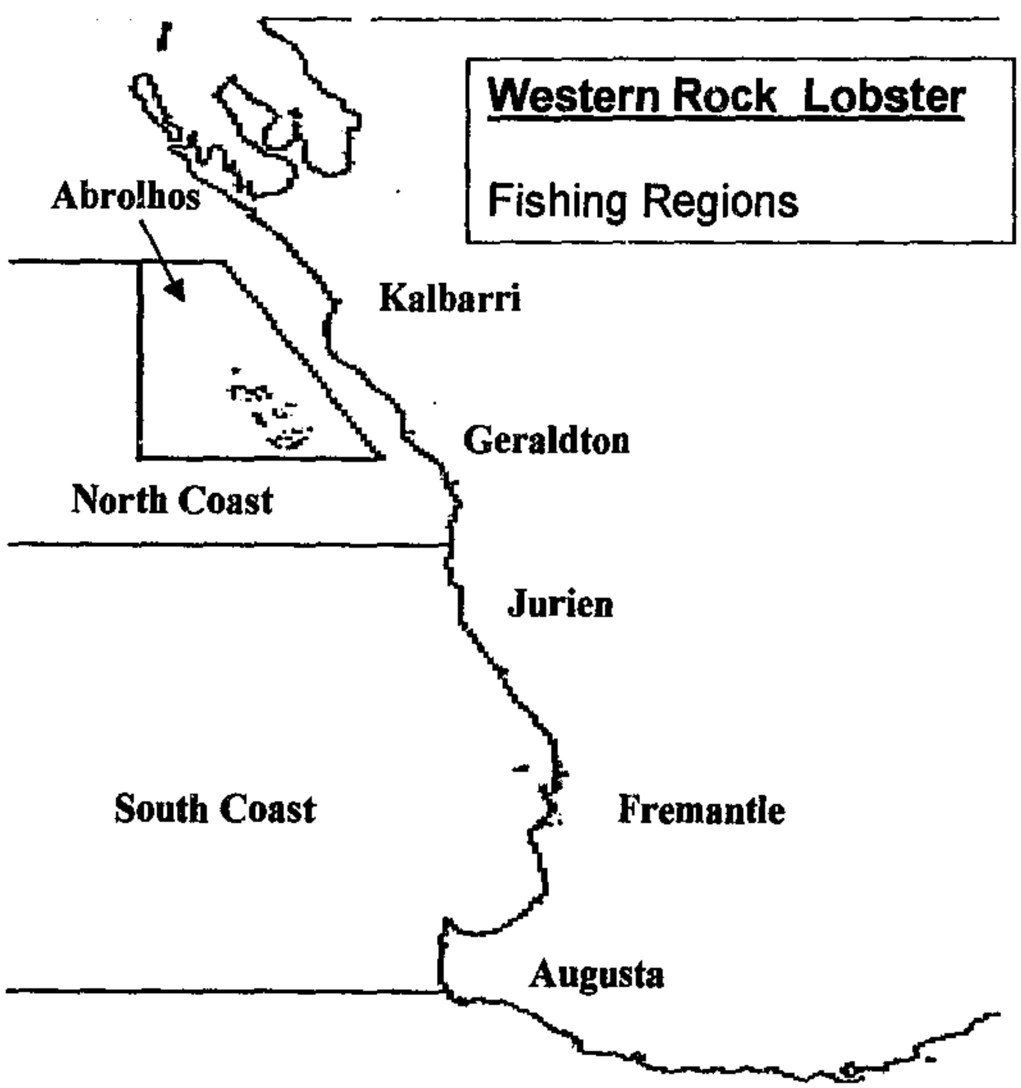


Figure 1.2 Map of Western Australia showing the three major fishing regions.

The data used have been obtained from voluntary research log books. The fishers have been providing this data to Fisheries Western Australia since 1964. The log books provide a detailed daily record including catch by depth and location, number of breeders and environmental conditions and are subdivided by 10 degrees latitude transects and five depth zones. The three major fishing zones are shown in Figure 1.2.

1.3 Thesis Aims

The aim of this thesis is to investigate the possibility of a cyclic pattern within the catch rate data of the western rock lobster and compare this to the lunar phase. Specifically we will be looking for a relationship between low catch rates and the full moon.

Catch rates for five consecutive seasons for the three main fishing zones are analysed. These seasons from 1993/94 to 1997/98 are further divided into two fishing depths from 0-20 fathoms, which is considered shallow waters and 20-50 fathoms, which is considered deep waters. A number of comparisons will be made using time series analysis. This will include comparing zones by year, zones by depth and zones by year and depth.

Three smoothing methods will be used to remove the underlying trend. These are moving averages, curve fitting and the Holt-Winters method (Winters). Once the trend has been removed we should be able to see the cyclic behaviour of the series. Decomposition and the Winters methods will be used to analyse the cyclic component of the series and the seasonal indices produced by these methods will be compared to the lunar cycle. Stock assessment is an important process in the management of the western rock lobster and cyclic behaviour may bias abundance estimates (owing to variations in catchability) and therefore the influence of such rhythms needs to be considered (Vance & Staples, 1992).

1.4 Thesis Outline

The time series methods used in this thesis are common and well documented in texts and therefore only a brief outline of these methods will be given. Chapter 2 will provide the theory and application of the time series methods. Chapter 3 presents the data sets. The results of the time series methods used on the western rock lobster data and their relationships to moon phase are discussed in Chapter 4.

1.5 Computer Software

Time series methods can be readily computed using existing software such as Microsoft *Excel* and *Minitab*. Moving averages were calculated using *Excel* spread sheets. Decomposition and the Holt-Winters method were all handled by *Minitab*. *TSA – 32* software was used to illustrate the application of spectral analysis.

1.6 Literature Review

Fisheries management papers provided some background of the western rock lobster and gave useful insight into the importance of the western rock lobster as a fishery as well as the problems associated in its management. Fisheries Western Australia has its own internet site and this provided both a brief history of the western rock lobster and up-to-date figures on the state of the fishery. Fisheries Research also provided a number of leaflets and brochures that included glossaries and further information on the fishing zones, seasons and restrictions placed on commercial and recreational fishing.

Information on time series is plentiful. Many of the texts relating to decomposition were in the area of business forecasting, however this made little or no difference to the methods used in this study. Some of the familiar names associated with time series included C. Chatfield, G. Janacek, P.B. Kenny and J. Durbin and A.C. Harvey. The text Introductory Business Forecasting by Newbold and Bos (1991) and Chatfield's The Analysis of Time Series (1996), were well studied.

The theory of spectral analysis and the operation of the *TSA-32* software is found in Henstridge (1993). Spectral analysis was found in many of the time series texts already mentioned including Priestley (1981).

The main problem was finding suitable literature on the environmental impact on fisheries using time series. Articles found came mostly from journals such as Marine and Freshwater Research and the Marine Ecology – Progress Series. A number of comprehensive articles were found that looked at environmental dynamics including influences such as the moon phase but were concentrated on larval or post larval organisms that lived in relatively shallow waters such as reefs and estuaries. These included Robertson, Swearer, Kaufmann and Brothers (1999), whose article examined settlement versus environmental dynamics in a pelagic-spawning reef fish at Caribbean Panama. Results varied depending on location and strength of the tidal effect, though fish with different pelagic larval durations all tended to settle around the new moon. Another article by Staples and Vance (1985), looked at influences on the immigration of postlarval banana prawns into a mangrove estuary. It found that 'the effect of moon phase...significantly affected postarval immigrations' although, overall, found that lunar phase was less important than the relation between tidal phase and timing of moonset and moonrise. An interesting article by Courtney, Die and McGilvray (1996) studied the lunar periodicity in catch rate and reproductive condition of adult astern king prawns. An article by B.F. Phillips (1975), looked at the intensity of moonlight on catches of the puerulus larval stage of the western rock lobster and found that the puerulus were only caught during the new moon phase. However, Phillips found that light intensity alone does not fully describe the pattern of puerulus settlement.

2. TIME SERIES

Some background to time series analysis is explained in this section. The components of time series analysis are briefly described. Different types of algorithms and methods that will be used are also briefly discussed in this section.

2.1 Introduction to Time Series

A time series is a collection of observations made sequentially in time (Chatfield, 1996). The physical sciences provide many examples of time series particularly in meteorology, marine science and geophysics. Air temperature or rainfall is a good example as the observations are aggregated over daily or monthly time frames.

Although time series can be continuous where observations are made continuously over time we will be only concerned with discrete time series where the observations are taken at equal time intervals. The appearance of the full moon is inherently discrete only appearing once every 29.5 days, while the catch rate is an aggregate (or accumulation) of the daily catch from a number of boats.

The special feature of time series analysis is the fact that successive observations are usually not independent and that the analysis must take into account the time order of the observations (Chatfield, 1996).

2.2 Components of Time Series

Time series can be decomposed into trend, seasonal variation, other cyclic changes and the remaining 'irregular' fluctuations. A brief outline is given below.

Trend can be thought of as change in the mean level over the observed time series. Seasonal effect is the variation in the time series which is annual in period. That is, the time series data displays a pattern, which is regularly found on a year to year basis. Other cyclic changes refer to the variation at a fixed period due to some other physical cause. Other irregular fluctuations, refers to the residual irregular or random effect. We will assume that the western rock lobster data is made up of trend, cyclic and irregular components.

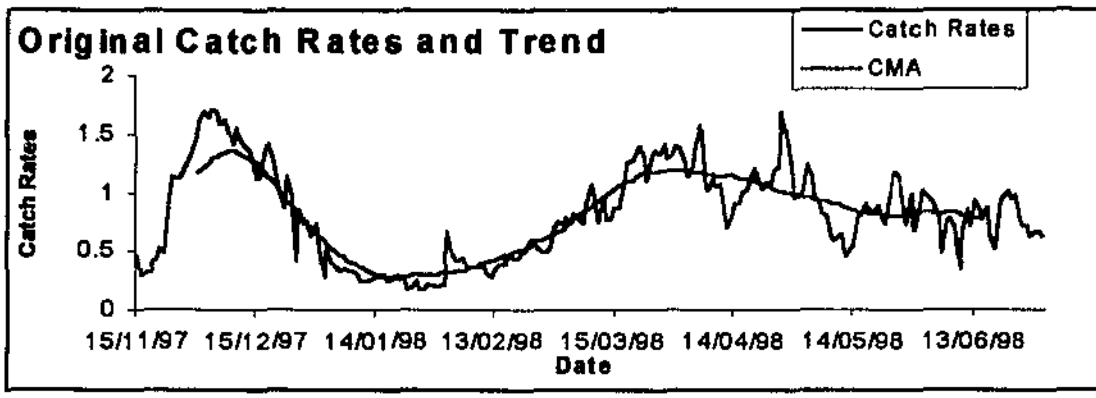
The time series can be represented by the sum or product of these three components. There are three models in common use. The model used depends on whether the data appears to be additive, multiplicative or a combination of the two. The multiplicative model is used when the size of the seasonal pattern in the data depends on the level of the data. This model assumes that as the data increase, so does the seasonal pattern. Most time series exhibit such a pattern. The multiplicative component model used by *Minitab* is

$$x_t = \text{Trend} * \text{Cyclical} + \text{Error}$$

and the additive components model is

$$x_t = \text{Trend} + \text{Cyclical} + \text{Error}$$

Our objective will be to break the series down into its components for individual study. Initially the trend will be removed which should allow the seasonal component to be observed. The seasonal component will be compared to the lunar cycle and the relationship if any, between the two analysed.



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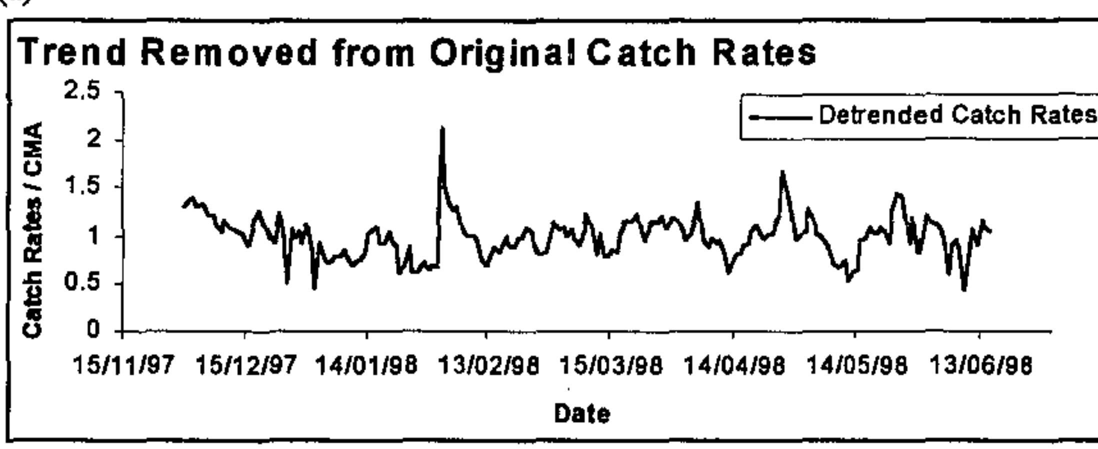

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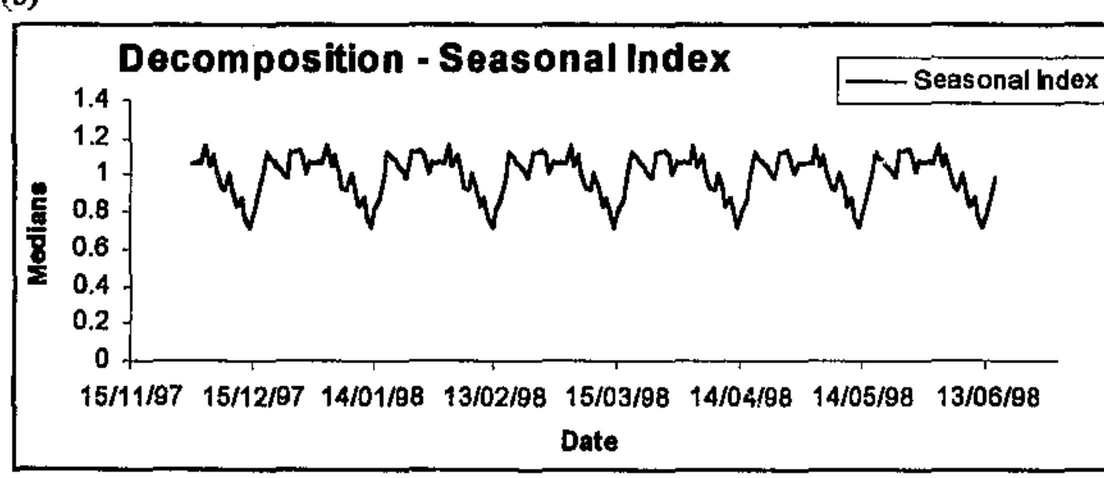

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Figure 2.1 Showing the trend and seasonality components from the catch rates for the series: 1997/98 season, shallow water, zone B. (a) Original catch rates with the smoothed trend line. (b) Trend removed from the original catch rates. (c) Seasonal component isolated from the original catch rates.

2.3 Data Sets

The time series data used in this thesis was kindly provided by Fisheries Research Laboratories, Waterman Western Australia. The data is collected from logbooks kept by the fishers and collated by Fisheries Research Laboratories. This data has been collected for many years, however only the last five seasons were considered for this analysis.

We specifically needed to look at the daily data in order to investigate cyclic behaviour. Previously, the average monthly data had been used for various types of analysis. Using daily data presented a number of problems. A small example of the raw data is shown in Table 1. This will be used to highlight some of the assumptions made and problems encountered.

Table 2.1 A section of the raw data taken from the series: season 1996/97, zone B.

Z	Date	Pull	0	10	20	30	40	Pot 0	Pot 20	Pot 20	Pot 30	Pot 40
B	19961125	1	8912	1225	0	0	0	9816	1420	0	0	0
B	19961126	1	10171	1665	0	0	0	9824	1495	0	0	0
B	19961127	1	11018	2288	0	0	0	9802	1616	0	0	0
B	19961128	1	11848	4245	0	0	0	8693	2510	0	0	0
B	19961129	1	12963	5240	0	0	0	8179	2964	0	0	0
B	19961130	1	13369	5105	40	0	0	7961	3219	26	0	0
B	19961201	1	11842	7993	526	0	0	6615	3921	218	0	0
B	19961202	1	11718	10861	1138	0	0	5925	4619	452	0	0
B	19961202	2	169	0	0	0	0	71	0	0	0	0
B	19961203	1	10597	9204		0	320	5349	4468	906	0	134
B	19961204	1	8402	9021	2197	123	350	4791	4521	1296	60	257

The data included the season, zone, and pull. The catch in kilograms and the number of pots lifted is given in five depths. The data comprised of five seasons from

1993/94 to 1997/98. Initially the fishing season 1992/93 was also to be included, however, a one off closure during the season meant that there was no data for one month. As this season varied greatly from the others, comparisons to the other seasons would have little meaning and therefore it was discarded.

Another problem encountered was the fact that the data was not sequential in time. Many days comprised of two or more data points. This is caused when pots are left in the water for more than one day. So, on any one day, pots could be pulled that had been in the water for one, two or more days. It was decided that only data from one pull days would be used. The reasoning is that if a cray pot was in the water for say, three days before it was pulled, to which day should the data be allocated. The catch could be averaged over the three days but then you are assuming that the same amount of lobsters are caught on each day.

Although the raw data set was separated into five different depths, Fisheries Western Australia suggested that the data should be separated into only two groups. These two groups are 0-20 fathoms and 20-50 fathoms and for this study they will be termed shallow and deep respectively.

Missing data or non-fishing days constituted the next problem, which is illustrated in Table 2.2. Reasons included public holidays and adverse weather conditions. Unfortunately fishermen are human and chose to take days off such as New Years Day and occasionally Christmas Day but not consistently over the five seasons or two depths. Other fishing days could have been possibly lost due to climatic conditions. To overcome this problem a simple averaging method was used. After the data was separated into the two depths it was found that the deep water had a lot of missing data at the beginning and the end of each season. Often the fishers did not fish the deep water until later in November. The end of the season often tapered off with fewer boats going out and the fishing days become inconsistent. In this case the cut off for the season was judged to be with the last consistent data. This has resulted in the deep-water series starting on different dates.

Table 2.2 Deep-water data (20 – 50 fathoms) separated from the raw data.

		Catch kg			Pot Lifts			Catch Rate
Date	Pull	20	30	40	Pot 20	Pot 30	Pot 40	20-50
25-Nov	1	0	0	0	0	0	0	#DIV/0!
26-Nov	1	0	0	0	0	0	0	#DIV/0!
27-Nov	1	0	0	0	0	0	0	#DIV/0!
28-Nov	1	0	0	0	0	0	0	#DIV/0!
29-Nov	1	0	0	0	0	0	0	#DIV/0!
30-Nov	1	40	0	0	26	0	0	1.5385
1-Dec	1	526	0	0	218	0	0	2.4128
2-Dec	1	1138	0	0	452	0	0	2.5177
2-Dec	2	0	0	0	0	0	0	#DIV/0!
23-Dec	1	445	19	195	490	52	270	0.8116
23-Dec	2	625	20	1236	993	33	1538	0.7336
23-Dec	3	175	0	115	206	0	54	1.1154
23-Dec	4	0	0	0	0	0	0	#DIV/0!
24-Dec	1	476	24	195	816	39	572	0.4870
24-Dec	2	379	32	550	487	60	820	0.7030
24-Dec	3	413	0	426	415	0	378	1.0580
24-Dec	4	0	0	0	0	0	0	#DIV/0!
25-Dec	1	0	0	0	0	0	0	#DIV/0!
25-Dec	3	44	0	0	123	0	0	0.3577
26-Dec	1	0	0	0	0	0	0	#DIV/0!
26-Dec	2	122	0	396	169	0	551	0.7194
26-Dec	3	552	0	245	619	0	409	0.7753
26-Dec	4	160	0	188	158	0	244	0.8657

The data comprises number of pot lifts per day and the total weight of the catch in kilograms per day. However, the data needs to be put into the form of catch rate and this is done by dividing the total catch for the day by the number of pots for the day. Now that the observations are sequential in time the catch rates could be calculated.

Catch Rates = Catch (kg) / Number of pot lifts

The catch rates are considered the original observations for the calculations used in all of the time series analysis methods.

A total of thirty time series were considered in this study. The way that the data was divided into the thirty data sets is shown in Table 2.3.

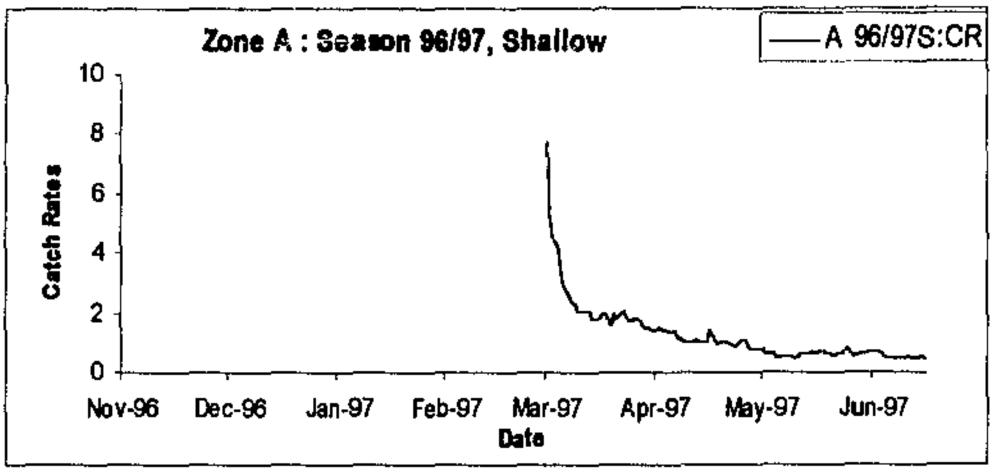
Table 2.3 Series for the western rock lobster.

	Season				
Depth	1993/94	1994/95	1995/96	1996/97	1997/98
Shallow	Zone A	Zone A	Zone A	Zone A	Zone A
	Zone B	Zone B	Zone B	Zone B	Zone B
	Zone C	Zone C	Zone C	Zone C	Zone C
Deep	Zone A	Zone A	Zone A	Zone A	Zone A
	Zone B	Zone B	Zone B	Zone B	Zone B
	Zone C	Zone C	Zone C	Zone C	Zone C

2.4 Catch Rates

A good place to start when considering an analysis of time series is to plot the data. Some of the properties and peculiarities of the different zones and depths can be illustrated by the time series plot. Figure 2.2 shows the time series plots for the catch rates of the 1997/98 season for shallow water for the different zones. Most of the features that are seen in these plots are also found in the series for the other years.

Zone A differs significantly from the other two zones mainly by the fact that the fishing season starts in March instead of November as with B and C and also by the very high catch rate values at the beginning of its season. Zones B and C are fairly similar. The features include high catch rates toward the beginning of the season. The time between the beginning of the season to around the beginning of January is when the lobsters migrate from shallow sheltered waters out to deeper waters. This is always a time of high catch rates, usually the highest for the season. This is followed by a period of low catch rates until February. The rest of the season has catch rates that fluctuate between these two extremes and the most likely period where a strong seasonal pattern may be found. There appears to be two distinct areas in the catch rate series for zones B and C, that is earlier part of the season to late January with very high fluctuating catch rates to the more stable pattern for the rest of the season. Analysing these two parts separately could lead to a better understanding of the data and also more significant results.



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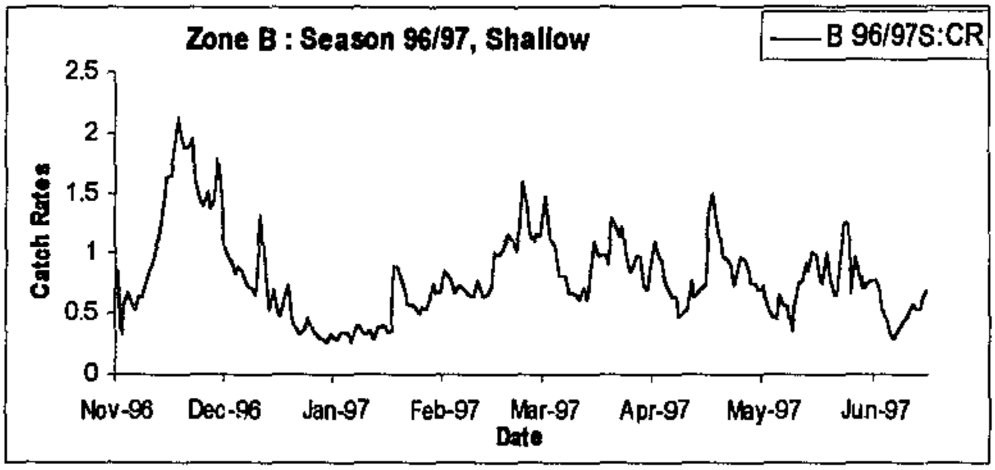

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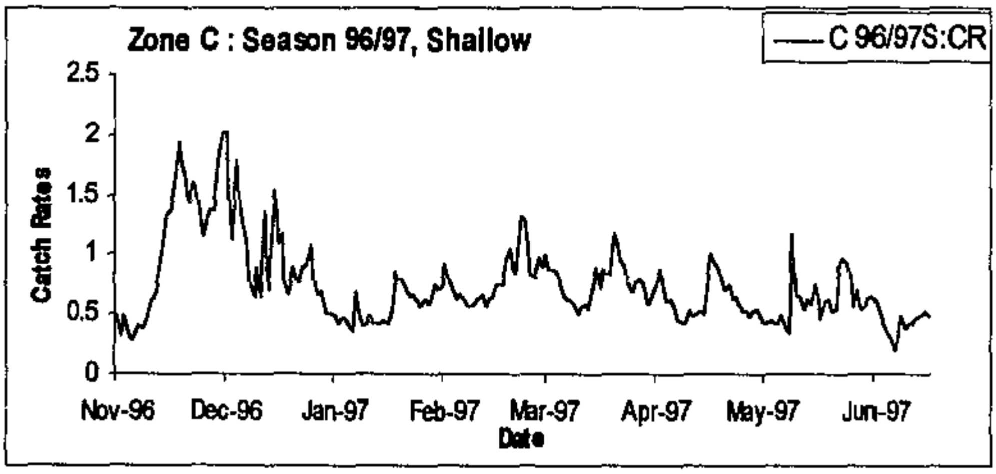


(c)

Figure 2.2 Catch rates for the 1996/97 season for shallow water separated into the three fishing zones, (a) Zone A. (b) Zone B. (c) Zone C.

3. METHOD

The research can be roughly broken into three parts. The first is to use various methods to remove the underlying trend from the data series. Secondly, we will use a number of methods to model the cyclic component of the time series, where this cyclic component will be compared to the lunar indices. Residual analysis forms the last part of the project, which will be used to test the effectiveness of the models. Comparisons will be made as to the goodness of fit between the various methods used.

3.1 Time Series Methods

The underlying trend is first removed so that cyclical effects, if any, may be examined. This allows the main features of the series to be captured without excessive detail (Kendall & Ord, 1990). The approach we will take is to decompose the data into its component parts. Usually these component parts are easy to see in a time series plot but at other times one component will overpower the other components. We want to investigate the possibility of a seasonal component but suspect that a strong trend component is present.

The methods that we are using can be generalised into two groups. These are static methods, which include the decomposition method and curve fitting using polynomials and dynamic methods which include the centered moving average method and the Winters method. 'Static methods have components that do not change over time while dynamic methods have components that do change over time where estimates are updated using neighbouring values.' (*Minitab*)

Decomposition separates the time series into linear trend and cyclical components as well as error. However, since the data are obviously not linear we need to remove the trend component first, then use decomposition to analyse the cyclic component. Moving averages smooth the data by averaging consecutive observations in a series. Deriving residuals by dividing the observed values by the centred moving averages we were able to remove the trend and these residuals were then used as the observed values for the decomposition method. Estimating a sixth degree polynomial and deriving the residuals by dividing the observed values by the fits were also used to remove the trend and were used in conjunction with the decomposition method. Lastly the Winters method was used which smooths the data by Holt-Winters exponential smoothing. *Minitab* allows us to choose whether the data is additive or multiplicative and therefore no prior manipulation of the observed values is required. The Winters method calculates dynamic estimates for three components: level, trend and cyclic.

Initially the Box – Jenkins ARIMA models were also going to be used in the analysis of the data. However, they were not chosen since we suspect that the series is dominated by trend and seasonality. The effectiveness of the ARIMA model is mainly determined by the initial differencing operations and not by the subsequent fitting of the ARMA model to the differenced series, even though the latter operation is much more time-consuming. Thus the simple models of moving averages, curve fitting and the Holt-Winters methods have been adopted. These models should be adequate for our data, since the series we are analysing display pronounced trend and large seasonal effect. These models have the advantages of simplicity, of being easy to interpret and of being fairly robust. However, some care must be taken since they usually assume the errors to be independent which is sometimes not the case (Chatfield, 1996).

For the three fishing regions, A, B and C we have five seasons of data. Each season is separated into two different depths, shallow water and deep water. Cyclic indices will be calculated for all of the series and these indices will be compared to the lunar phase. First quarter, full moon, last quarter and new moon are the four stages of the lunar phase.

3.2 Model Selection

Our aim is to model the cyclic component of the western rock lobster time series. There are many modeling techniques to choose from. Which methods are chosen depends on a number of factors including the properties of the series as assessed by a visual examination of the data, the number of observations available and the way in which the model is to be used (Chatfield, 1996).

The first step in time series modeling is to plot the observations against time. This will show up important features such as trend, cyclic behaviour, discontinuities and outliers (Chatfield, 1996). Figure 3.1 shows the 1996/97 catch rates for the western rock lobster. The most distinguishable feature is the non-linear trend and the jagged appearance is a result of the irregularities in the data. We also note that the observations appear to be multiplicative.

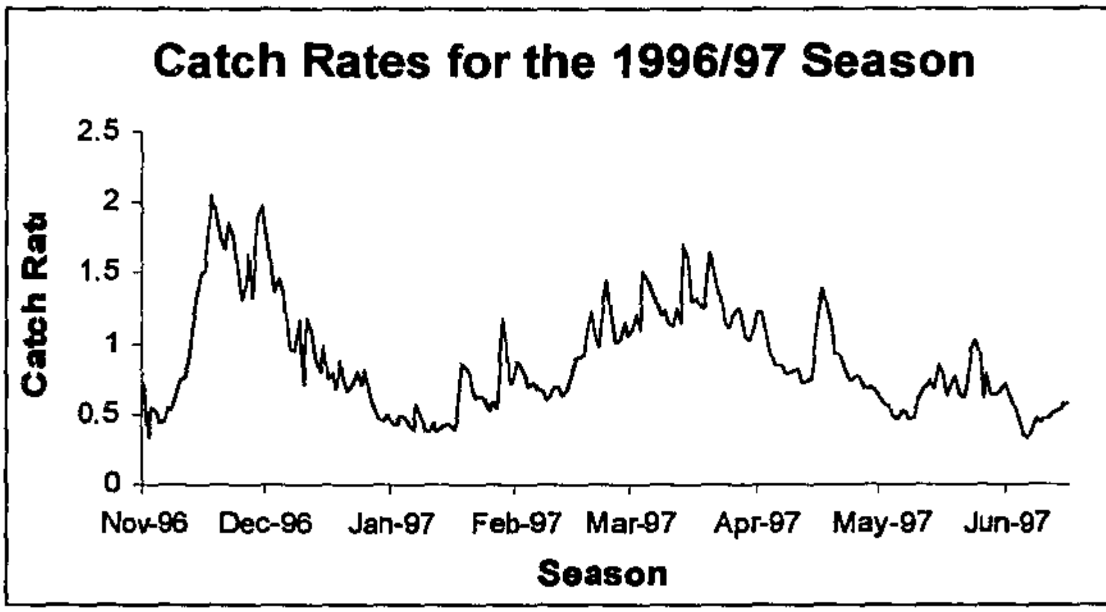


Figure 3.1 A time series plot showing the catch rates for the western rock lobster 1996/97 season.

3.3 Estimating Trend

The approach that we need to take involves estimating the values of the individual components. Since the data displays a strong trend component we will endeavour to model the trend first in order that it can be removed from the data so that a cyclic component may be observed. Many approaches to this problem have been proposed and implemented (Newbold & Bos, 1990). The methods we have chosen to deal with the removal of trend are moving averages and curve fitting. Once the trend has been removed then other methods such as decomposition and the Holt-Winters method will be used to estimate the cyclic component.

Another way of looking at the time series is in the frequency domain. A common procedure in time series is to estimate the spectral density function. The spectrum describes how the variation in a time series may be accounted for by cyclic components at different frequencies (Chatfield, 1996). We will use the spectrum to show that the series has a cyclic component even though it may not be evident from the time series plots.

3.3.1 Moving Averages

Moving Averages can be used to yield estimates of the trend component. This is often referred to as smoothing the series. By smoothing the series we get a clearer picture of the trend pattern. A thirty-point average was chosen since it produced a smooth line through the data. This is achieved by averaging all sets of thirty consecutive values of the original series.

In general, where the moving average chosen is based on an odd number of observations then for any positive integer m, the *simple centred* $(2m + 1)$-*point moving average* of the time series $X_1, X_2, \ldots, X_n$ is given by

$$X_t^* = (X_{t-m} + \ldots + X_{t-1} + X_t + X_{t+1} + \ldots + X_{t+m})/(2m + 1)$$

$$(t = m+1, \ldots, n - m)$$

However, because we are using an even number (30) the value for the new series is centred between two time periods from the original series. In order for the values of the new series to correspond with the original series we average adjacent pairs of values of the series X_t^*.

The general formula is

$$X_t^{**} = (X^*_{t-.5} + X^*_{t+.5})/2 \qquad (t = 3, \ldots, n-2)$$

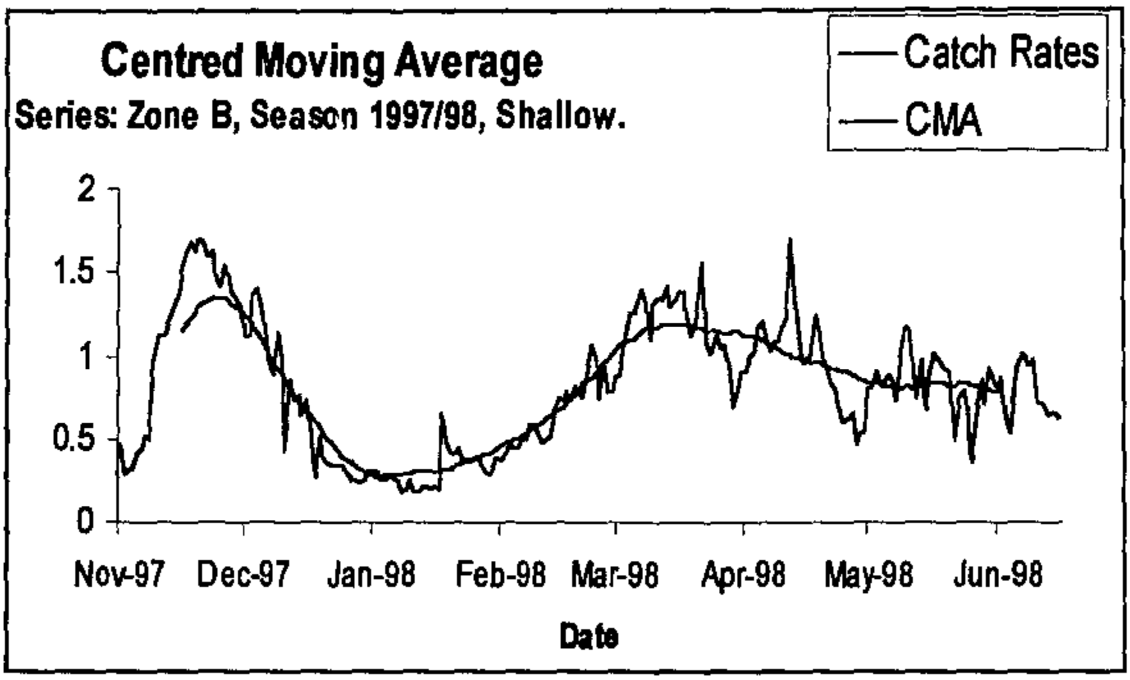


Figure 3.2 A time plot of the original catch rates and the trend after the series has been smoothed using the centred moving average method.

We note that m observations are lost at either end of the smoothed series. This however, is not a problem at this stage since there is enough data remaining to give us an indication of a cyclic component. This would be a problem if we were specifically concerned with the beginning data or if the analysis was required for forecasting where the values at the end of the data would be required.

3.3.2 Curve-fitting

Another method of analysing data that contain trend is to use a simple function such as a polynomial curve. This method is usually used to deal with non-seasonal data, however, though we suspect that the data contain a cyclic component, we only want to use this method to remove the trend component and once the trend has been removed we can use another method to analyse the cyclic component. *Excel* will add a trend line to a time series plot and we used this to determine which degree the polynomial required in order to give an adequate fit to the series. It was found that a 5^{th} degree polynomial could not adequately predict the tail end of the series and so a 6^{th} degree polynomial was used to estimate the trend. However, the associated formula given by *Excel* was not accurate enough to reproduce the trend line. Using multiple regression in *Minitab* we were able to calculate the fits for a sixth degree polynomial.

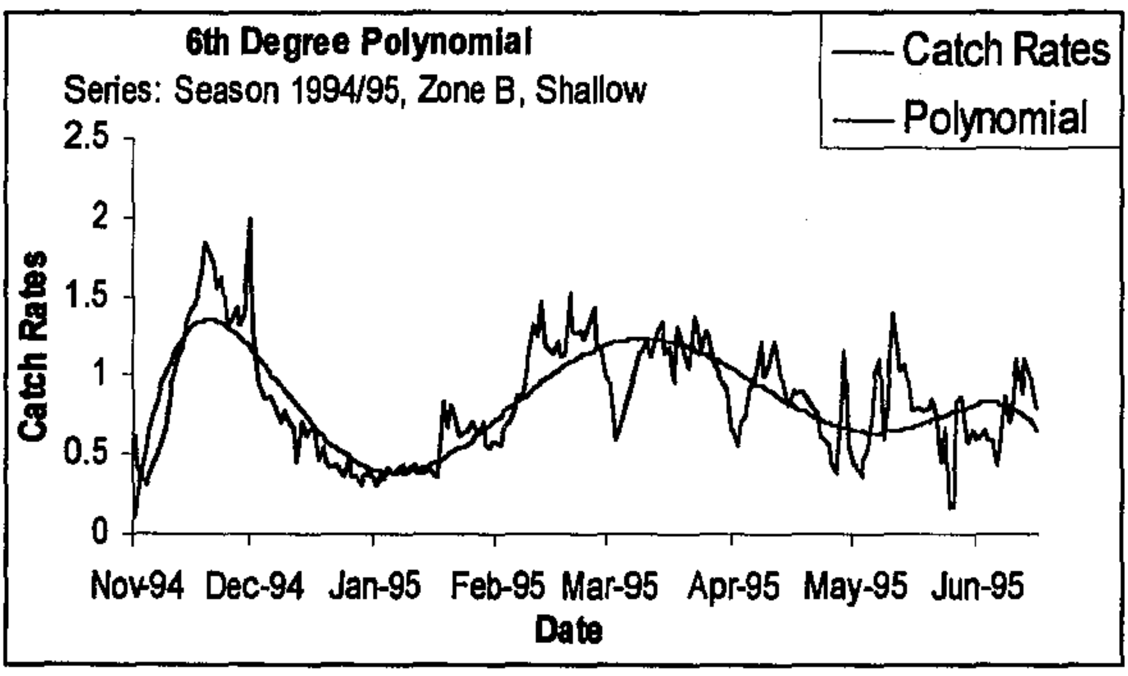


Figure 3.3 Time plot of the catch rates and the trend line resulting from a 6^{th} degree polynomial.

One result from estimating the trend using a 6^{th} degree polynomial is shown in Figure 3.3.

Multiple regression calculates the least squares fit through the original catch rate values by using the following equation:

$$Y = b_o + b_1X_1 + b_2X_2 + ... + b_kX_k + e$$

where b and k are constants.

The fitted function given by the curve provides a measure of the trend and the residuals provide an estimate of local fluctuations, where the residuals are the differences between the observations and the corresponding values of the fitted curve (Chatfield, 1996). Now that the trend has been identified we can remove the trend from the time series and this will hopefully allow the cyclic nature of the data to be identified and analysed.

3.4 Detrending

The trend is removed from the original catch rates in order that the cyclic component may become 'visible'. If the series were additive the detrended data would simply be the residuals, that is, the original catch rate series minus the smoothed series. However, the series are multiplicative and this means that the detrended data is calculated as follows,

Detrended Series = Original catch rates / smoothed series. (trendline)

The decomposition method can be used to estimate the cyclic indices with two sets of detrended series.

Detrended CMA = Original catch rates / Centred Moving Average

Detrended Polynomial = Original catch rates / Polynomial

3.5 Cyclic component

The cyclical component captures periodic oscillatory behaviour as opposed to seasonality, which is annual in period (Newbold & Bos, 1990). The cyclic component can be analysed using a number of methods such as the Holt-Winters method and Classical decomposition. These methods all refer to seasonality in the series, however, in the rock lobster series the seasonal component is replaced by the cyclic component.

3.5.1 Decomposition

There are three models commonly used to decompose a time series. These are

(1) the additive components model

$$X_t = T_t + C_t + I_t$$

(2) the multiplicative components model

$$X_t = T_t\, C_t\, I_t$$

(3) a combination of the additive and multiplicative components models

$$X_t = T_t\, C_t + I_t$$

Here T is the trend component, C is the cyclic component and I is the irregular or error component.

The decomposition command in *Minitab* performs a classical decomposition on a time series using either a multiplicative or an additive model. Classical decomposition separates the time series into trend, cyclic and error components by using least squares analysis, trend analysis and moving averages. When a multiplicative model is chosen *Minitab* adopts the combination formula.

Unfortunately, the decomposition model in *Minitab* does not give you the option of choosing the type of trend but simply assumes a linear trend. Therefore, if the series is not linear you have the option of transforming the series into a linear trend or estimating the non-linear trend and removing the trend from the data before using the decomposition command in *Minitab*. The decomposition method allows you omit the trend component from the decomposition.

3.5.2 The Holt – Winters Method

The Holt-Winters procedure generalises the process of Exponential smoothing which allows it to model time series containing trend and seasonal variation. This procedure can be used for data containing both trend and cyclic components with these components being either additive or multiplicative.

Firstly we need to decide whether the cyclical component is to be taken to be additive or multiplicative. From an examination of the time series plots we will assume that a multiplicative seasonal effect is more appropriate. This means that the higher values have greater variation in the level than the lower values. Often both the additive and multiplicative models are tried and compared and the better model used. Secondly we need to estimate the three smoothing parameters.

Let L_t, T_t, and C_t denote the estimates for level, trend and cyclic components, given observations x_t on a time series and let α, γ, δ denote the three smoothing parameters for updating the level, trend and cyclic index respectively. The smoothing parameters are usually chosen between 0 and 1. The algorithm employs a new observation to update previous estimates with a recurrence form using weighted averages (Newbold & Bos). The updating equations are as follows,

$$L_t = \alpha (x_t / C_{t-s}) + (1-\alpha)(L_{t-1} + T_{t-1})$$

$$T_t = \gamma (L_t - L_{t-1}) + (1-\gamma) T_{t-1}$$

$$C_t = \delta(x_t / L_t) + (1 - \delta)C_{t-s}$$

Here x_t / C_{t-s} is the deseasonalised data and s is the length of the seasonal cycle. eg s =12 for yearly and monthly data.

If a larger weight is used for a smoothing parameter then a more rapid change will result in that component and smaller weights will result in less rapid changes (*Minitab 12* n.d.). For each new observation the values for L, T and C are updated.

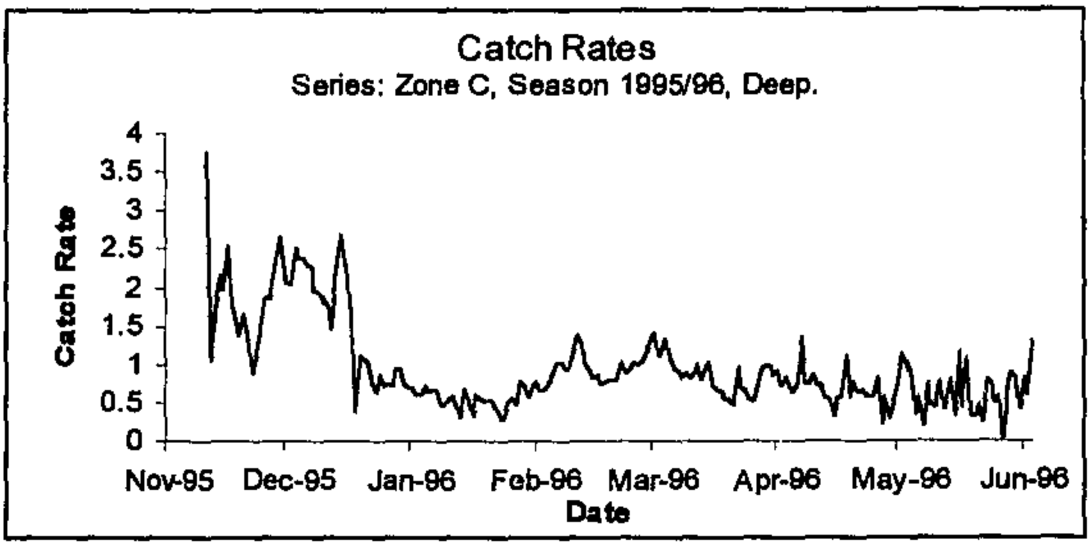


Figure 3.4 Catch rates for the 1995/96 season, zone C, deep water.

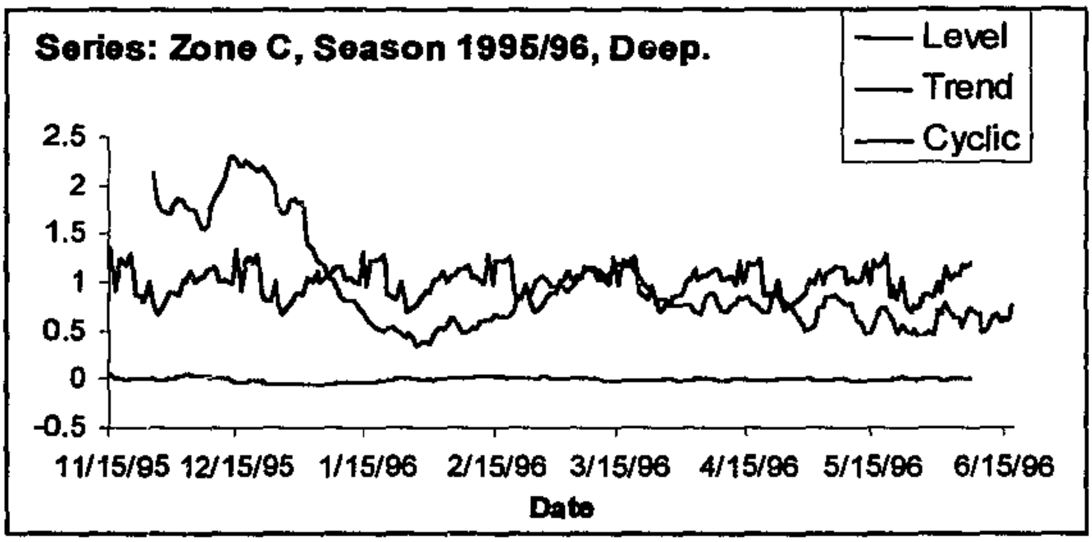


Figure 3.5 Winters method showing level, trend and seasonal estimates.

Figure 3.4 shows the graph of the original catch rate data. There appears to be little or no discernible cycle and any trend would not be considered linear. The Winters method decomposes the data into the components of level, trend and cyclic indices and these results are shown in Figure 3.5. Our main focus will be on the cyclic indices, which will be calculated for all of the catch rate series and compared to the lunar phase.

4. DATA ANALYSIS

This section looks at the data using the processes previously described. Not all results will be detailed here because of the large number of data sets used. However all results are to be found in the appendix. Results and examples have been limited to particular years, seasons, zones or combinations of these, where this limited number was found to adequately clarify or highlight the results attained.

4.1 Comparison of Detrending Methods

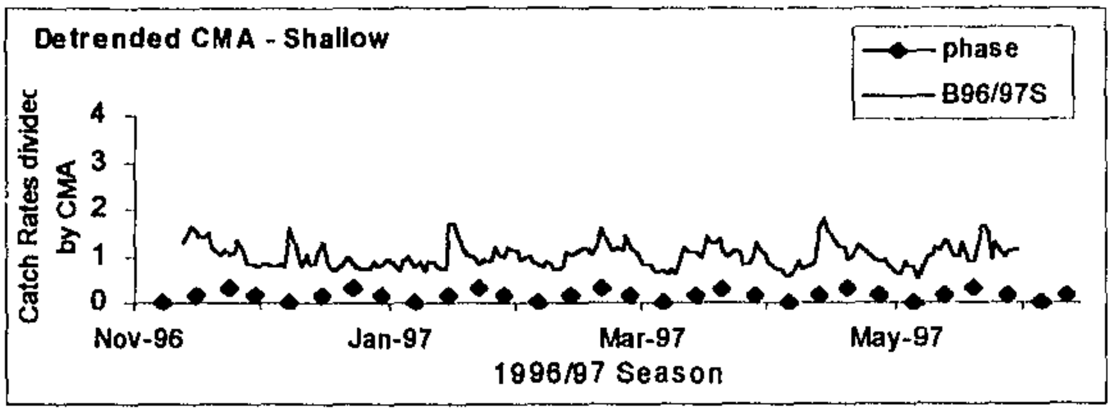
The trend is removed from the original catch rate data by dividing the catch rate by the estimated trend values. The estimated trend values are divided rather than subtracted since we are assuming that the catch rates display multiplicative behaviour. The multiplicative model is used when the size of the cyclic pattern in the data is proportional to the level of the time series (Newbold & Bos, 1990). This is only required for the centered moving average (CMA) and the polynomial methods since the Winters method defined by *Minitab* calculates the time series components simultaneously.

The 1996/97 season, Zone B for both shallow and deep water have been used to show an example of the detrended series for the CMA and polynomial methods. The detrended series using the CMA and polynomial methods were plotted against the actual moon phase dates that correspond to the 1996/97 season. The blue diamonds in the graphs in Figure 4.1 represent the four phases of the moon. The diamond with the value zero represents the date when the full moon appears.

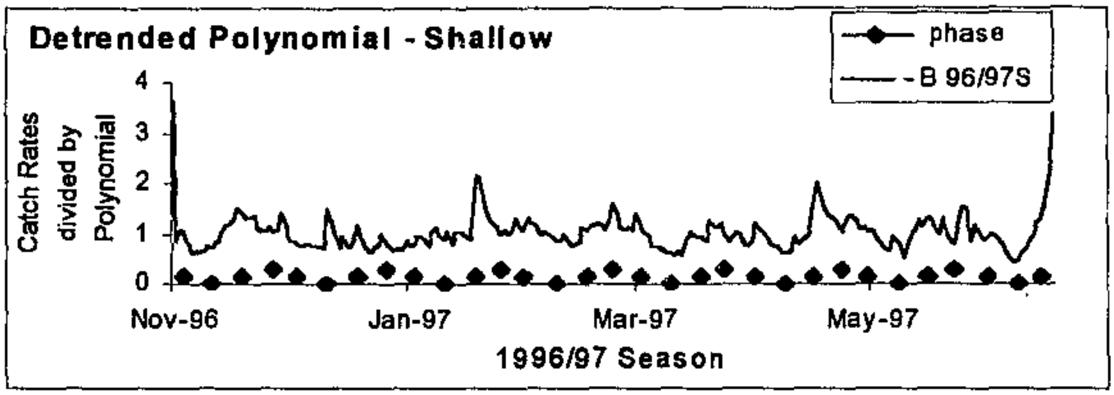
The graphs display several features. Beginning with the detrended CMA series for shallow water shown in Figure 4.1 (a) and Figure 4.1 (c), we can see that the CMA have missing data at both ends of the series due to the way the method calculates the trend. The series appears to have a weak cycle with local minima roughly coinciding with the full moon phase from the 15th of March 1997. The detrended polynomial series shown in Figure 4.1 (b) and Figure 4.1 (d) also have problems at the ends of the series caused by ill fitting estimates of the trend at these points, however as with the CMA there appear to be a cycle forming after the 15th March 1997.

The main feature in the deep-water series is the peak around the 14th February 1997 that coincides with the opening of the Big Bank fishing region. The fishers starting their season later than the official opening date is another reason for the missing data at the beginning of the season with the deep-water data. This can be as much as thirty days after the official opening date. From a visual perspective there appears to be little difference between the two methods. The polynomial method was used as a comparison to ensure that by using a 30 point centered moving average we were not forcing the data into a 30-day cycle. The similarity of the detrended series for both of these methods gives credibility to the use of the 30-day centered moving average method.

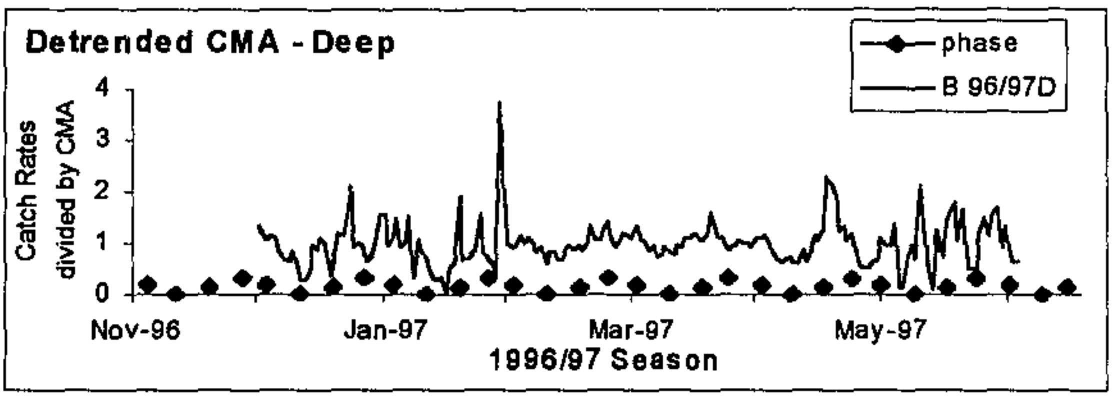
Although there appears to be a weak cycle forming from March to June with the shallow water data it would be difficult to make any generalisation about the deep water. However, we can explore the detrended series further by looking at the data from another perspective. The spectral density function is an excellent tool, which can be used to search for cyclic behaviour.



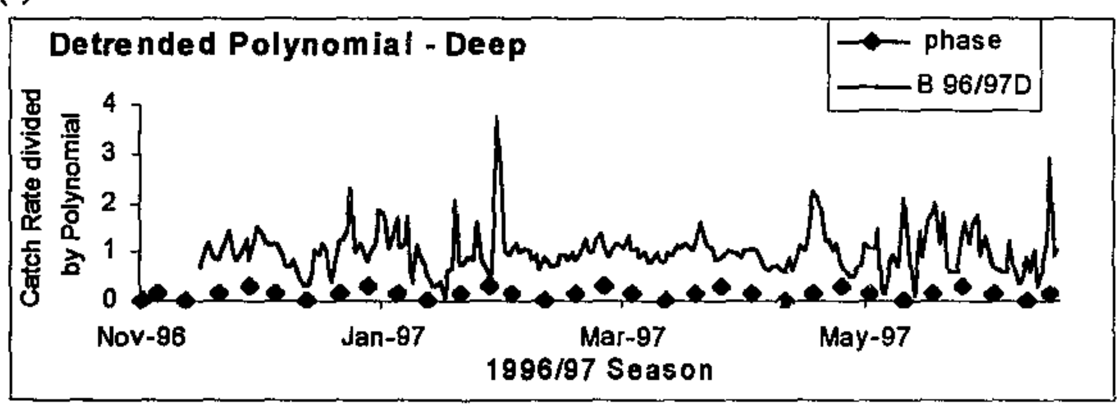
(a)



(b)



(c)



(d)

Figure 4.1 Detrended series for zone B, season 1996/97, compared to the four moon phases. (a) CMA method: shallow water. (b) Sixth degree polynomial: shallow water. (c) CMA method: deep water. (d) Sixth degree polynomial: deep water.

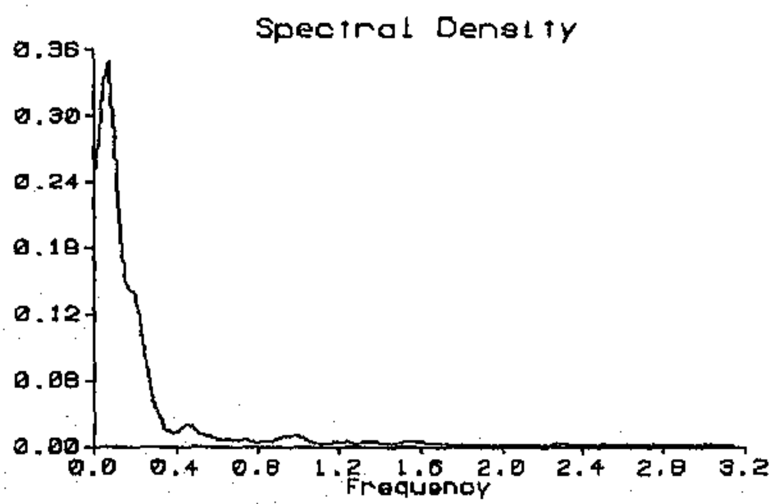
4.2 Spectral Density Function

The use of the spectral density function allows us to analyse the data in another way thereby allowing us to draw conclusions from another source. The software that is used to plot the spectral density function is *TSA – 32*. The x-axis is the frequency measured in radians and the total area under the curve is equal to the variance of the process. A peak in the spectrum indicates an important contribution to variance at frequencies in the appropriate interval.

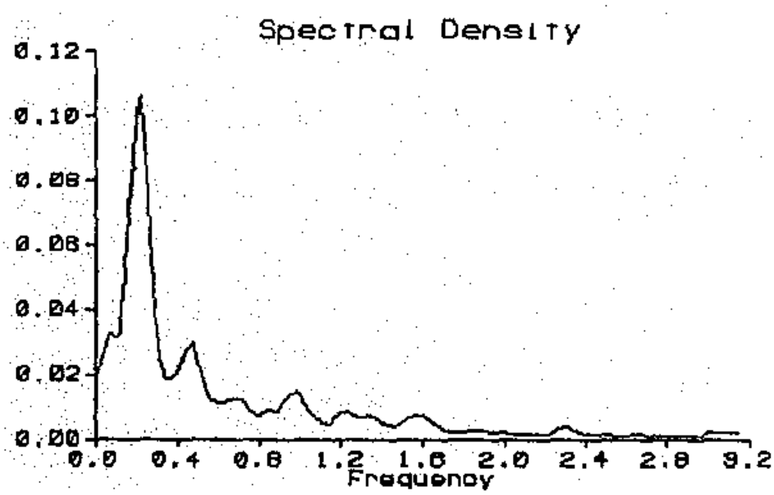
In Figure 4.2 (a) and Figure 4.3 (a), where the catch rates for the 1996/97 season have been plotted, we can see that the variance is concentrated at low levels. This indicates a possible strong trend component. The trend component completely overshadows any cyclic behaviour. This contrasts to Figure 4.2 (b) and Figure 4.3 (b), where the trend has been removed from the catch rate series using the CMA method. Here the peak corresponds to $\omega = 0.205$ for the shallow series and $\omega = 0.213$ for the deep series. If we refer to frequency as $f = \omega/2\pi$, that is the number of cycles per unit time then we have a form of frequency that is much easier to interpret from a physical point of view (Chatfield, 1996). Then the period, called the wavelength, is $1/f$ and we can calculate this period in the following manner,

$$1/f = 2\pi \ / \ \omega$$

By using this formula the detrended shallow series corresponds to a cycle of 30.6 days and the detrended deep series corresponds to a cycle of 29.5 days. The observed lunar month is 29.531 days. This result for the deep water is surprising since we could not discern any cycle from the time series plot of the detrended data. This shows the advantage of using the spectral density function where periodicy is suspected. By plotting the spectral density function we have confirmed that cyclic behaviour is present within the time series and is significantly close to the lunar month cycle to warrant further investigation.

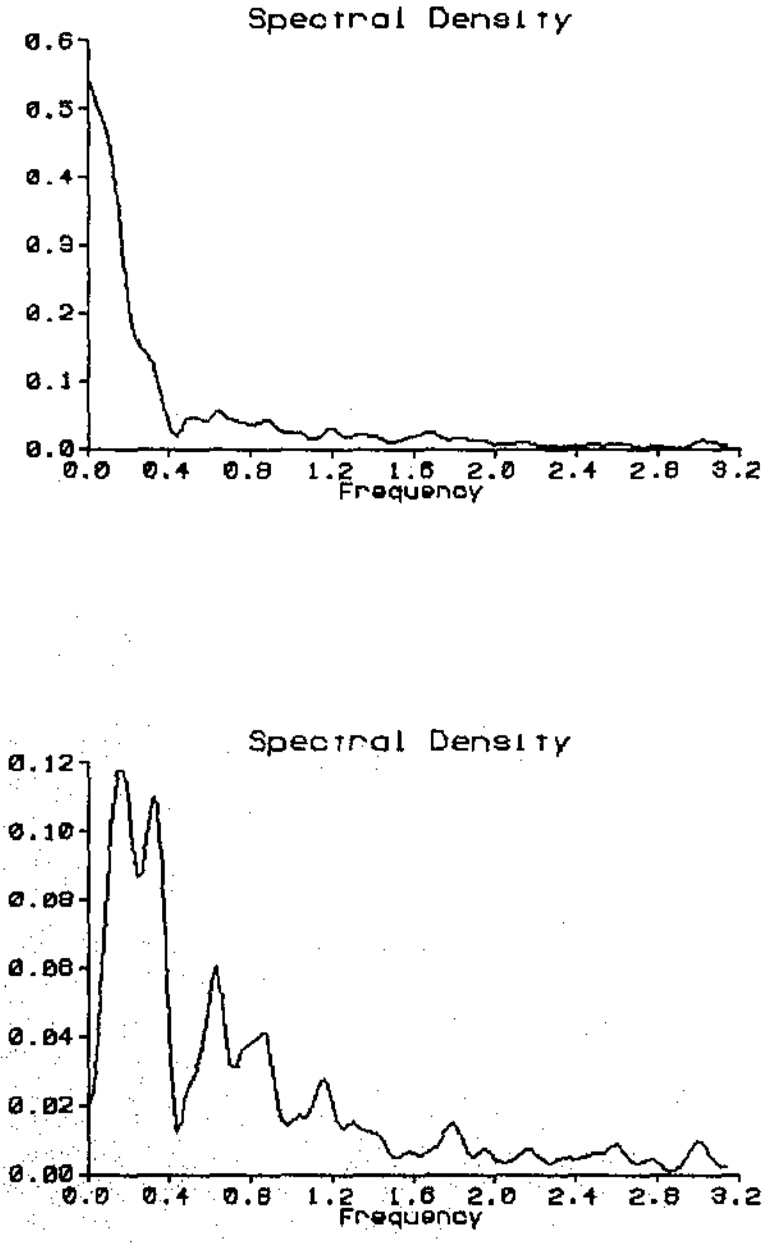


(a)



(b)

Figure 4.2 Spectral density plots. (a) Catch rates for zone B, season 1996/97: shallow. (b) Detrended series using the centered moving average method for zone B, season 1996/97: shallow.



(a)

(b)

Figure 4.3 Spectral density plots. (a) Catch rates for zone B, season 1996/97: deep. (b) Detrended series using the centered moving average method for zone B, season 1996/97: deep.

4.3 Cyclic Indices

The detrended series that was produced by the CMA method and the polynomial curve will now be used to estimate the cyclic indices using the Decomposition method in *Minitab*. The series had to be detrended since the Decomposition method, when using *Minitab* software, assumes a linear trend and the Western Rock Lobster series does not display linear trend. Therefore, the Decomposition method was only required to calculate the cyclic indices and error. We will also use the Winters method to estimate the cyclic indices. The Winters method uses the original catch rate series. As an example of the results cyclic indices medians are plotted for the 1996/97 and the 1997/98 seasons for all zones, that is A, B and C (see Figure 4.4).

It needs to be pointed out that zone A has only four months of data, which are reduced to three months after using the CMA method. The CMA method loses data at both ends of the series. This creates the problem of the median being calculated from only three values, therefore, care needs to be taken when drawing conclusions based on the results, particularly in zone A.

The first step is to plot the cyclic indices to get an indication of the shape of the cyclic series over the whole season. As an example the cyclic indices were plotted for the 1996/97 season using the shallow series. Zones B and C were graphed to allow us to compare the results derived from the three methods, which are shown in Figure 4.4. In general the series display a non-symmetrical shape. One of the features is the sharp recovery after the minimum value has been reached and this is apparent in all of the graphs in Figure 4.4. The CMA and the polynomial series are reasonably similar with the main difference found in the peaks.

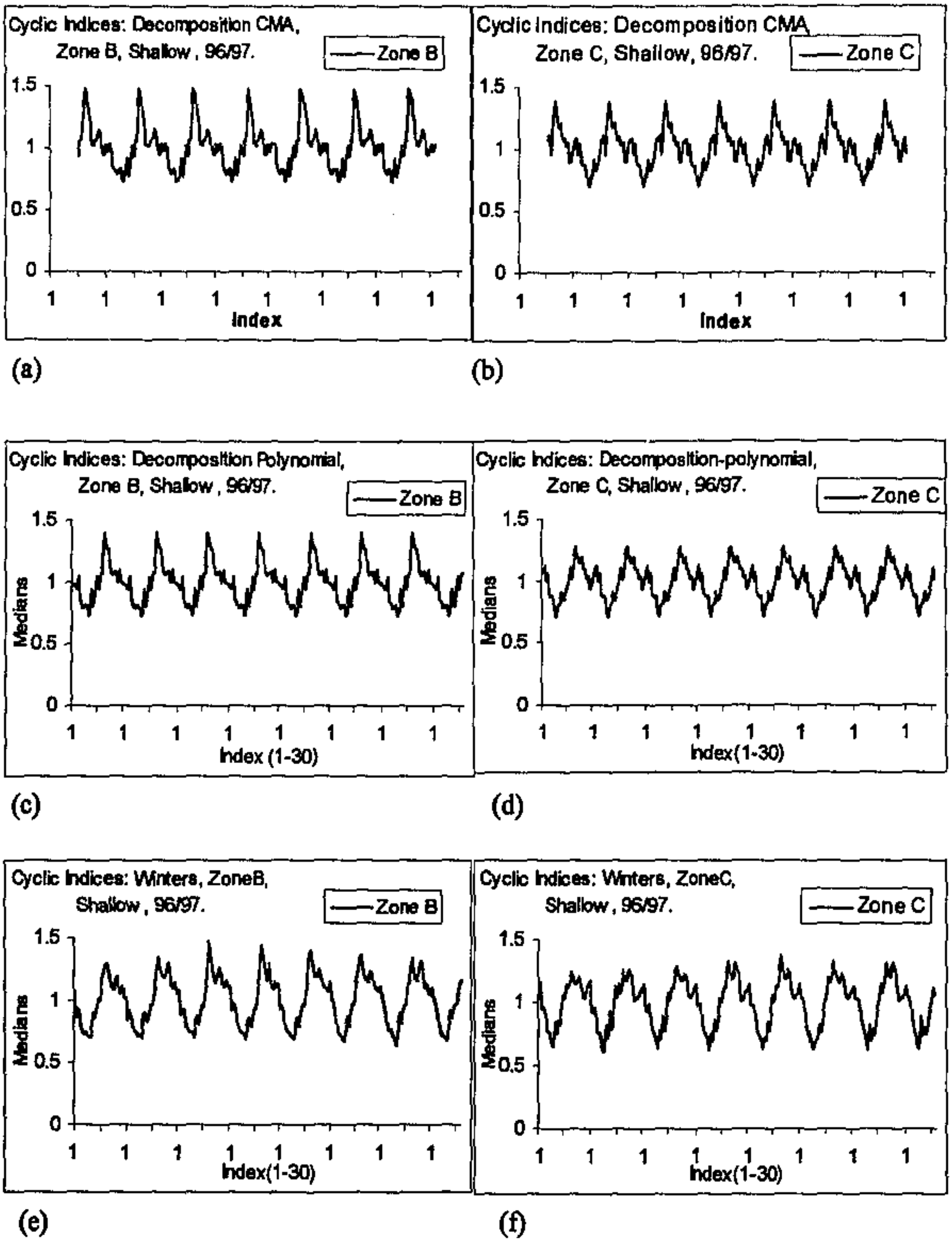


Figure 4.4 Cyclic indices for shallow water for the 1996/97 season.
(a) Zone B: Decomposition method for the detrended CMA series. (b) Zone C: Decomposition method for the detrended CMA series. (c) Zone B: Decomposition method for the detrended polynomial series. (d) Zone C: Decomposition method for the detrended polynomial series. (e) Zone B: Winters method. (f) Zone C: Winters method.

The CMA method in Figure 4.4 (a) and (b) results in higher peaks than the polynomial method and the minimum values appear to be fairly constant over all methods. The Winter's method is a dynamic method where the cyclic indices are allowed to change over time.

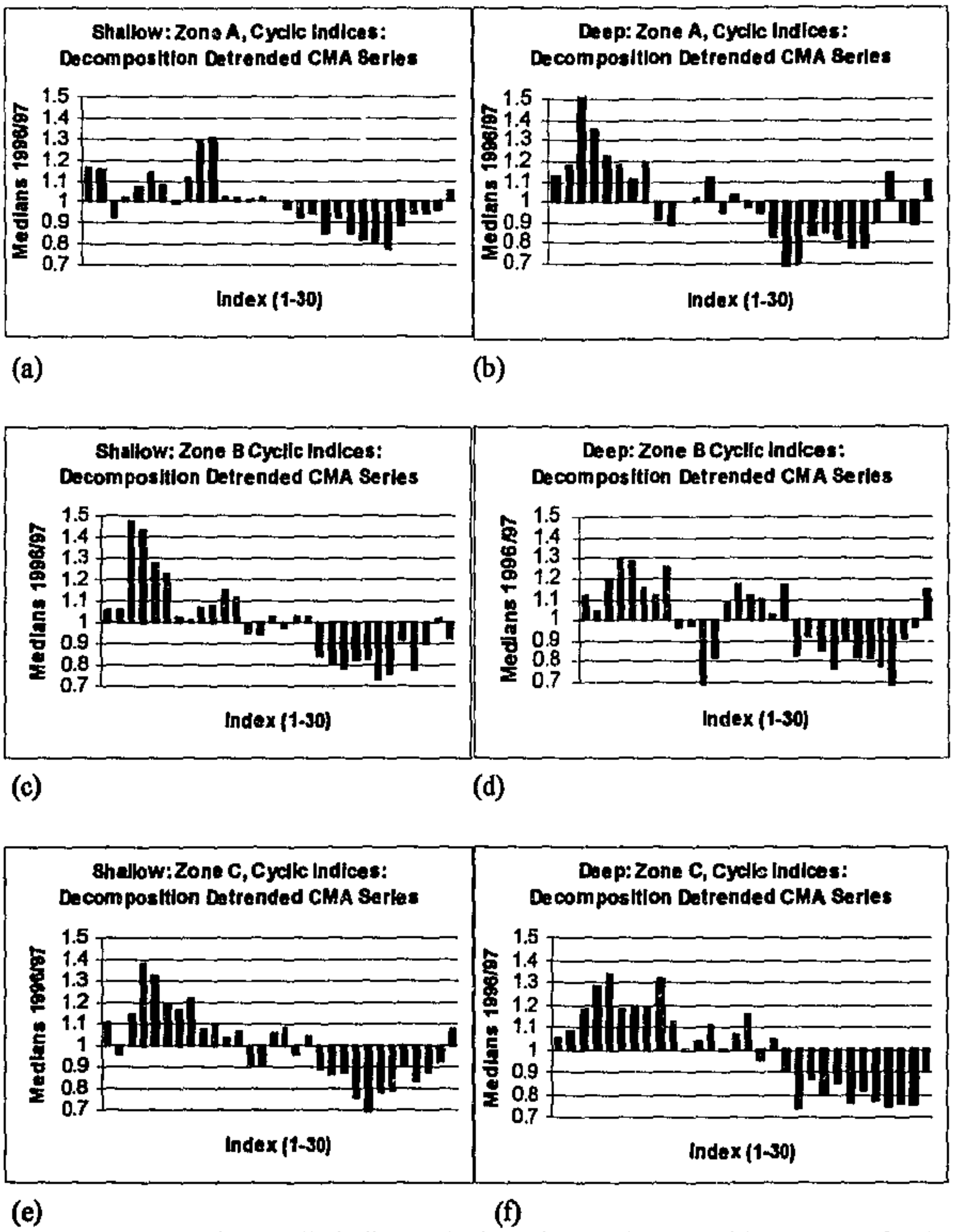


Figure 4.5 The thirty cyclic indices calculated by the decomposition method for the 1996/97 season. (a). Zone A, shallow water. (b) Zone A, deep water. (c) Zone B, shallow water. (d) Zone B, deep water. (e) Zone C, shallow water. (f) Zone C, deep water.

It is interesting to note that the values of the peaks in the Winters method vary between the values of the other two methods. For all three methods over the two zones the minimum and maximum values all fall at the same index.

Decomposition calculates the median value of the raw seasonal values found. The medians are further adjusted so that their mean is one. These adjusted medians constitute the cyclic indices. Since we have stipulated a 30-day cycle the decomposition method calculates 30 cyclic indices and repeats the same 30 indices over the length of the season. The indices for the 1996/97 season have been plotted for the three zones, shown in Figure 4.5.

The shallow series for the 1996/97 season displays a similar shape for all of the zones. The medians in Figure 4.5 (a), (c) and (e) which represents the shallow water show that the cycle has a stronger shape than the data representative of the deep water. We can see that for each shallow water plot that there is a generally smooth transition from medians greater than the mean (the mean being equal to one) to medians that are less than the mean. We can say that in general the medians greater than one are grouped together for half of the 30 day cycle and the medians lower than one are also grouped together. The medians greater than one corresponds to the new moon phase and the medians lower than one corresponds to the full moon phase.

The medians in Figure 4.5 have been plotted so that they approximately correspond to the days of the month. However, because the months have different lengths the median is calculated from a spread of three days. That is, for example, the fourth median is calculated from the value corresponding to the second third or fourth day of the month. Now the actual dates of the full moon for the 1996/97 season also fall on varying dates from the 21st to the 25th inclusive, due to the lunar month of 29.5 days. If we compare the medians to the actual dates of the full moon then we see that for the shallow water the lowest median values fell within this period. Low median values for the deep-water data also corresponded to the full moon period.

4.4 Dividing the Season into Two Parts

Earlier we looked at the detrended series for the 1996/97 series, Zone B. One of the noticeable features of this series was that the data at the beginning of the series appeared more random than the rest of the series. The beginning of the fishing season corresponds to the juvenile western rock lobster moulting into adults and migrating out to deeper water. This migration happens in November and December and produces high catch rates that drop off consistently until January when the lowest catch rates are recorded. The rest of the fishing season is a time of non-migratory lobster. Inspecting plots of the detrended CMA series against the cyclic indices one can see this variability in the series more clearly. All of the seasons displayed this behaviour to varying degrees. A good example is shown in Figure 4.6.

The series to around the 15th of February shows more variation than expected. That is, the fit is not as good, particularly when compared to the rest of the series. Decomposition calculates the 30 cyclic indices from all of the available data, so what would happen to the results if we separated the earlier part of the series from the rest of the series and calculated the cyclic indices in two separate parts?

By decreasing the series to just a few months we have the same problem as we did with Zone A with only a few months to calculate the medians. Zone A was not used in this analysis due to the small length of the fishing season. We wanted to maximize the amount of data with which to work, therefore, the Winters method was considered the better choice. The CMA method lost data at either end of the series and the polynomial method had problems estimating data at the beginning of the season.

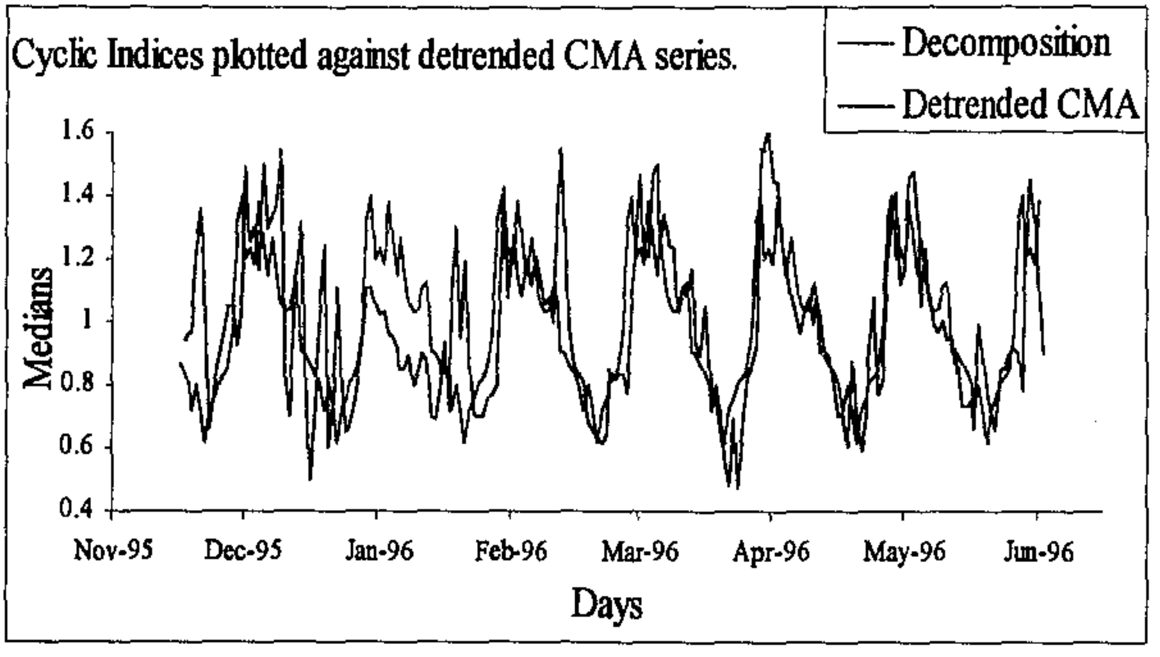


Figure 4.6 Cyclic Indices compared to the detrended CMA series for the 1995/96 season, Zone C: Shallow water.

An appropriate cut off date had to be chosen. This date would be sometime during January or February between the transition from migrating to non-migrating lobster where the catch rates 'bottomed out'. The cut off date chosen was the 31st January for each season. A typical result is seen in Figure 4.7, where the original Winters cyclic indices calculated from the whole season are mapped against the separately calculated indices. The early part of the season runs from the 15th of November until the 31st January and the late part of the season runs from the 1st February until the 30th June.

There is clearly a difference between the cyclic indices of the early part of the season compared to the cyclic indices for the remainder of the season. The early part of the season displays higher medians at the peaks and more fluctuations moving from the lowest median to the highest. The most distinctive difference is the double point at the low medians. The late section of the series shows a very stable 30-day cycle, whereas previously using all of the data for the season we saw that the values changed for different 30-day cycles.

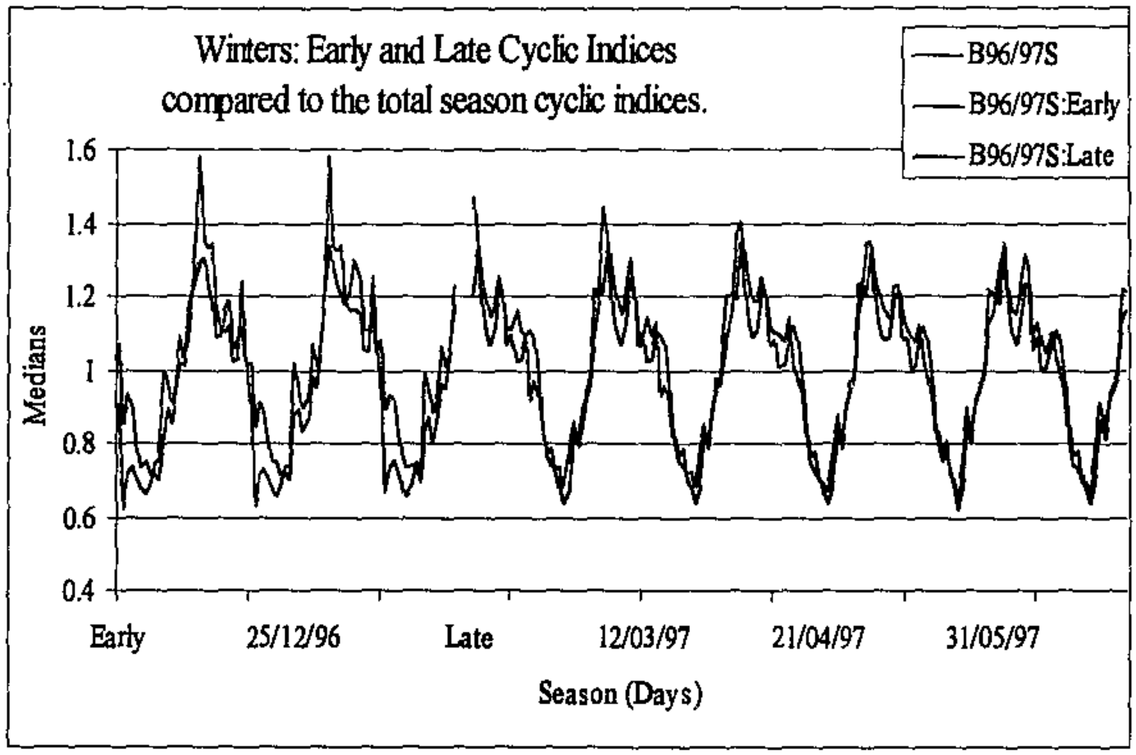


Figure 4.7 Comparison of early and late indices to the original indices calculated over the total length of the 1996/97 season for zone B, in shallow water.

By taking out the influence of the earlier part of the season the late cyclic indices display a very stable pattern with a very distinct minimum median around 0.6. So by separating the season into two parts, the early and the late, we take out the influence that one has over the other and we find that these two parts in fact display quite different cyclic patterns.

4.5 LUNAR PHASE

The *lunar month* is the time between two successive alignments of the Moon with the sun, observed from the Earth, and usually taken from the time between successive new Moons. The average lunar month is 29.531 days, variation from this value can be up to 13 hours (Heiken, Vaniman & French, 1991).

During the lunar month, differing proportions of the moon's visible surface are illuminated by the sun. The *phases of the moon* are four specific instances in this process. The four phases of the moon are new moon, first quarter, full moon and last quarter. The full moon occurs when the apparent longitudes of the moon and sun differ by 180 degrees and 100 percent of the moon's visible surface is illuminated, while during the new moon phase the moon does not appear to be illuminated. The first and last quarter have 50 percent of the moon's visible surface illuminated (Definitions of Astronomical Events, 1999).

Initially, we considered comparing the actual dates of the full moon with the cyclic indices calculated. This created a problem. Though most of the indices showed a distinctive monthly minimum, this point did not always match up with the full moon date within the same season. This is inherently caused by the fact that we are trying to compare a 30-day cycle with an average 29.5 days in a lunar month. One way to overcome this is to divide the lunar month into four sections. To do this each phase is taken over seven days, that is the actual date of each phase ± three days (Courtney, et al, 1996). It was found that all the minima fell into the full moon ± three day category.

4.6 The Winters Method Compared to Moon Phase

In this section we look at the fishing season data that has been divided into two parts, 'early' and 'late' as described in section 4.4. The original catch rates were used since the Winters method calculates dynamic estimates for all three components, level, trend and seasonal. The Winters method was chosen mainly because this method uses all of the data available.

The moon phase has been allocated arbitrary values so a comparison can be made graphically. The value allocated to the full moon is 0 and for the new moon the value is 0.3. For the purposes of analysis each lunar phase, new moon, first quarter, full moon and third quarter spanned seven days. That is a three-day period centered on the full moon versus the rest of the month (Robertson et al., 1999). Each quarter was represent by a dash at the value allocated.

The results have been tabled and each graph was categorised as to whether minimum indices coincided with the full moon quarter. At this stage we are only making comparisons with the full moon phase. Where the series showed a strong contrast between low and high values and where these low values match with the full moon a category of '1' was allocated. Where the pattern was not so distinct but low values were still found within the full moon quarter a '2' was allocated and where no pattern was found a '3' was allocated.

Table 4.1 Shows the results of using the Winters method on catch rate data for each season that has been divided into 'early' and 'late'.

		Zone B, Shallow			Zone C, Shallow		
Season	**E/L**	**1**	**2**	**3**	**1**	**2**	**3**
1993/94	E			x	x		
1994/95	E	x				x	
1995/96	E		x			x	
1996/97	E			x	x		
1997/98	E			x	x		
1993/94	L	x			x		
1994/95	L	x			x		
1995/96	L	x			x		
1996/97	L	x			x		
1997/98	L	x			x		
		Zone B, Deep			**Zone C, Deep**		
year	**E/L**	**1**	**2**	**3**	**1**	**2**	**3**
1993/94	E			x	x		
1994/95	E		x			x	
1995/96	E			x		x	
1996/97	E	x				x	
1997/98	E		x		x		
1993/94	L			x		x	
1994/95	L		x			x	
1995/96	L	x				x	
1996/97	L			x		x	
1997/98	L	x			x		

E = early; early part of the season from 15th November to 31st January.
L = late; latter part of the season from 1st February to 30th June.
1 = where the minimum value falls in the full moon quarter.
2 = there is more than one minimum value, however a local minimum falls with in the full moon quarter.
3 = no minimum values fall in the full moon quarter.

Table 4.1 has been displayed to help identify any similarities between zones or years or depths. From this table we can quickly identify the areas where the indices closely follow the moon phase and where they do not. Zone C appears to have low indices corresponding to the full moon quarter over all years and for both depths with a particularly clear cycle in the shallow water in the latter part of the season. Zone B however, is less decisive for all but the results for shallow water in the latter part of the season. To give a better understanding of how the results were catergorised into '1', '2' and '3' a few examples are given graphically. Figure 4.8 is typical of the strong cycle where the indices are high during the new moon and low during the full moon.

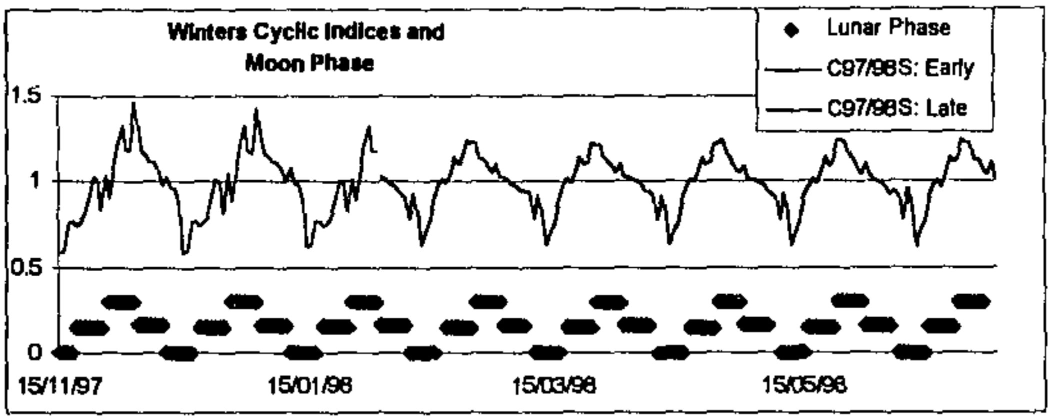


Figure 4.8 Cyclic indices calculated using Winters method showing a smooth transition from high indices around the time of the new moon to low indices during the full moon quarter.

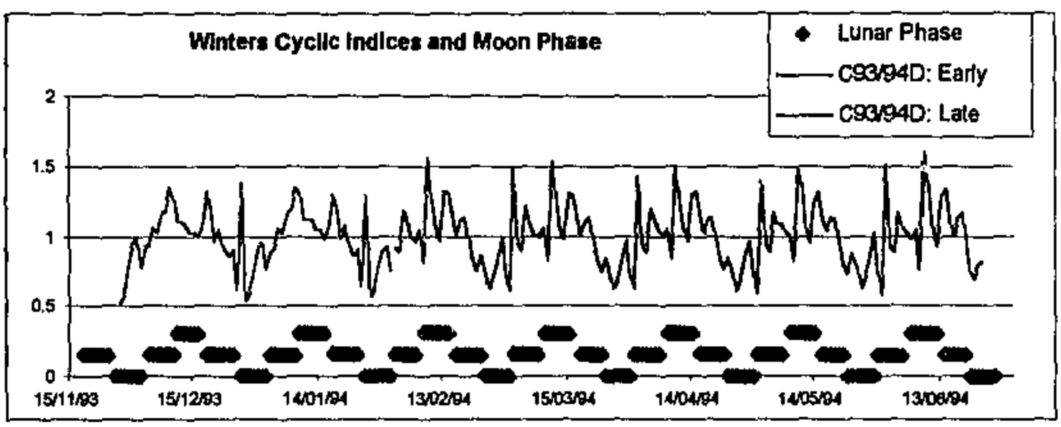


Figure 4.9 Shows cyclic indices calculated using Winters method that display a more erratic behaviour but the series still has low values around the full moon quarter.

Figure 4.9 shows cyclic indices that also have low values during the full moon but not exclusively at this time. The series appears more erratic though still vaguely follows the pattern of high values during the new moon quarter and low values during the full moon quarter. In fact, Zone C deep largely fell into this category.

Interestingly, Zone B displayed results where higher indices were recorded around the time of the full moon quarter, however it was never over the whole of the season but rather either in the earlier part of the season or the latter. Figure 4.10 gives an example of this behaviour.

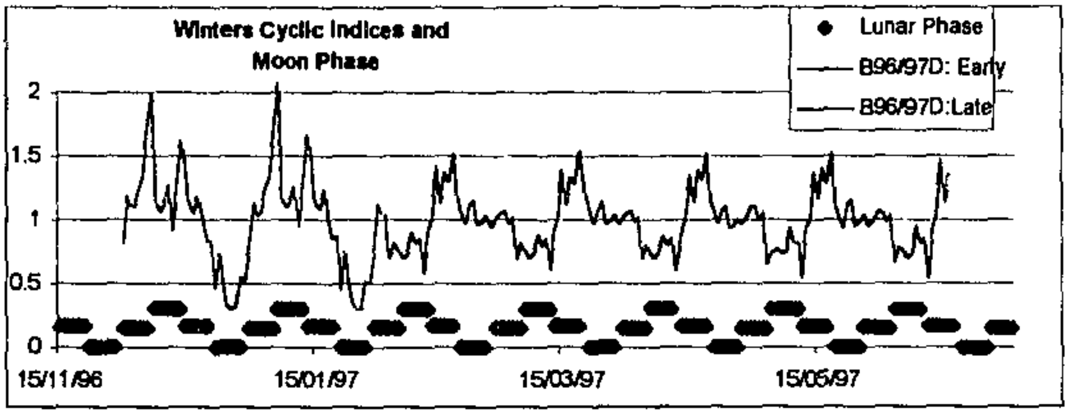


Figure 4.10 Cyclic indices calculated using Winters method for the 1996/97 season Zone B, deep water, where the latter part of the series does not have minimum indices around the time of the full moon.

So far we have concentrated purely on the full moon quarter but we are also interested in what is happening during the rest of the lunar month. Figure 4.11 to Figure 4.13 show some of the results. They represent the five seasons and the indices calculated for the four lunar phases.

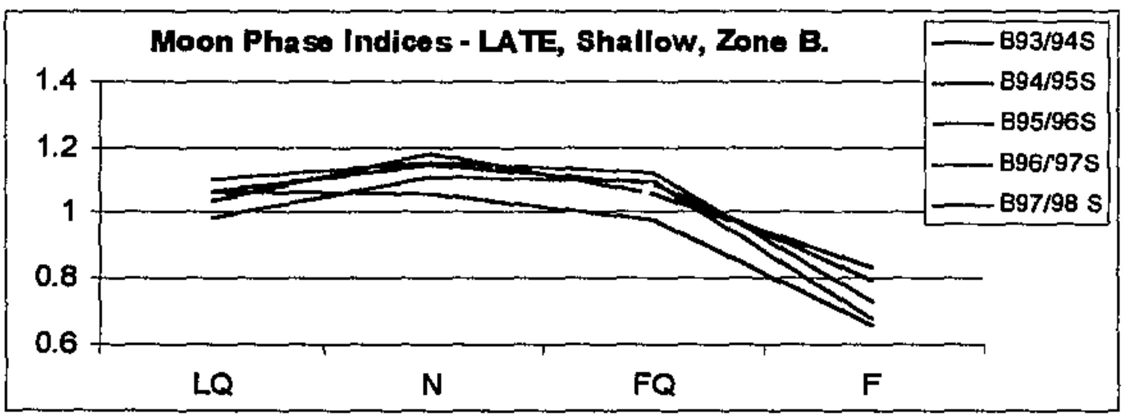


Figure 4.11 High indices coincide with the new moon and low indices coincide with the full moon.

Figure 4.11 shows how, not only do we get low values during the full moon but also high values during the new moon and there appears to be a smooth transition between the two. These results were found for all years and both zones in shallow water in the latter part of the season.

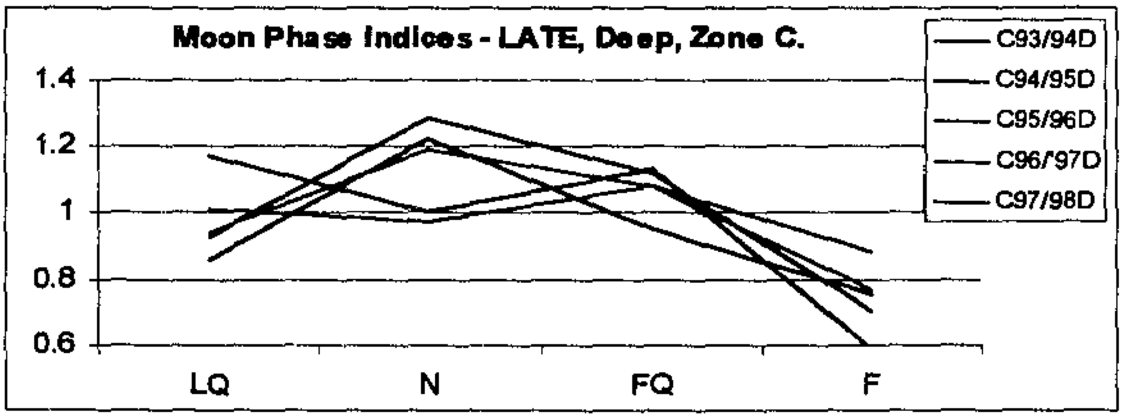


Figure 4.12 Low values are found during the full moon but high values do not always coincide with the new moon.

Figure 4.12 shows results that were typical for most of zone C where the graphs showed a somewhat erratic style though minimum values did coincide with the full moon.

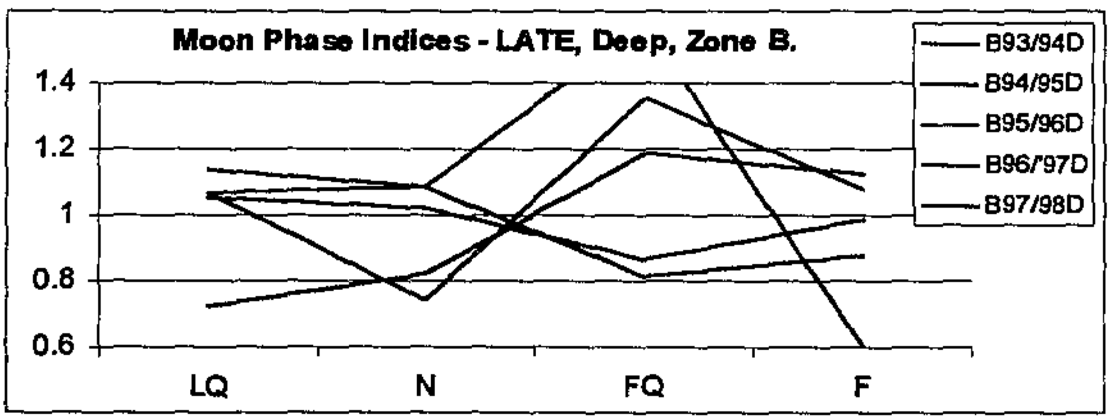


Figure 4.13 Zone B for deep water for the late part of the season displays more random results.

By separating the catch rates into 'early' and 'late' we have further refined the process. We can see from both the table and the graphs that there are distinct differences between the two. This may have to do with the biological cycle of the western rock lobster or changes in weather patterns moving from summer to winter. Finding the reason for this result is not a part of this thesis, but the aim is to identify these differences. We have found that of the forty series investigated using the

Winters method to identify the cyclic component that thirty two showed low values usually around the 0.8 mark or lower that coincided with the full moon quarter.

4.7 Comparison of all Three Methods

Lastly we will compare the results from the three methods against the indices that coincide with the full moon phase. Recapping, the three methods used are (a) decomposition of the detrended centered moving average method, (b) decomposition of the detrended 6^{th} degree polynomial and (c) the Winters method. For this comparison we used the Winters method with the whole of the season data. The index chosen was the lowest index within the period three days either side of the actual full moon date. The results in Figure 4.14 show the indices as a percentage which represents the difference between the index and the mean. As previously mentioned the Winters method and the Decomposition method both calculate the median rather than the mean and then the thirty medians are adjusted so that their mean is equal to one.

For shallow water, Zone B and Zone C the results were stable with little variation between the three methods for the five seasons analysed. The greatest variation was found for Zone A in both shallow and deep water, which may be a result of the limited number of months of the fishing season. Because of the shortness of the season the process becomes sensitive to variations in the data. However, all methods over all zones, years and depths showed indices that were below the mean, with reductions that varied between 15 percent and 44 percent with 84 percent lying between 20 and 40 percent.

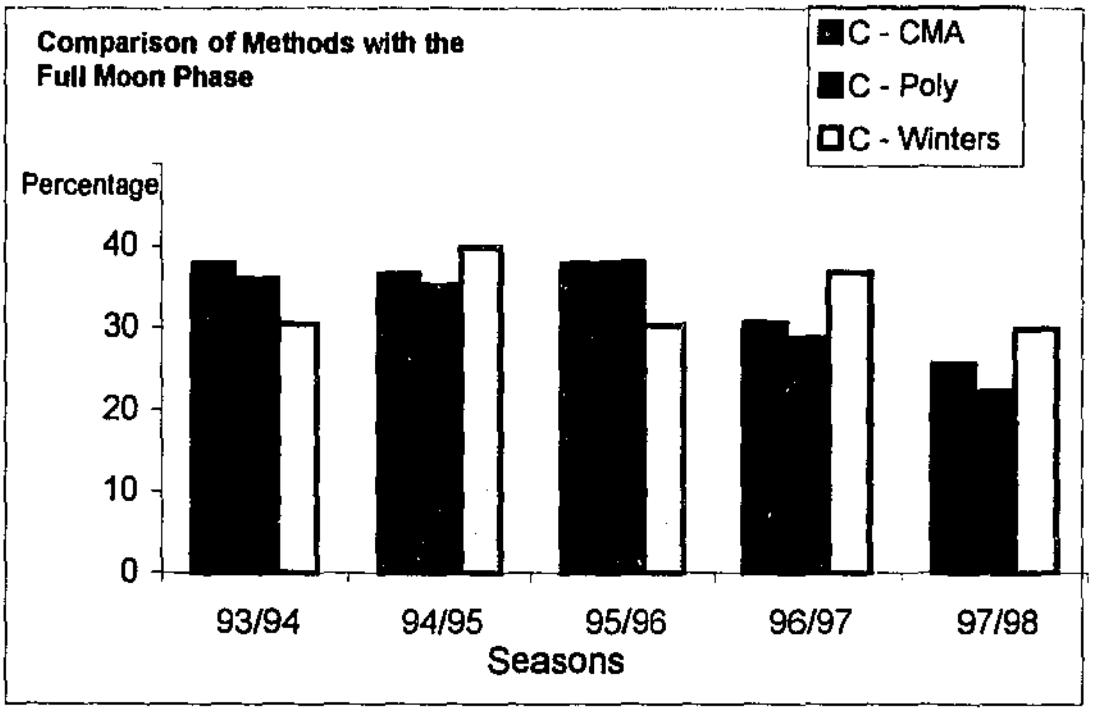


Figure 4.14 Comparison of the percentages (index less mean) for the full moon phase, resulting from the three methods over all the five seasons.

5. DISCUSSION AND CONCLUSION

The aim of the thesis is to take the available data and to fashion it in such a way that it can accurately be compared to the moon phase so that the results can also be assumed to be reliable. It was hoped that by using numerous series this would give us a good picture of the behaviour of the data. In fact this study is more of a preliminary analysis where the aim is to get a grounding into the behaviour of the data that is to be analysed. This is largely due to the fact that very little analysis has been done in this area and it is hoped that this study will lead to more advanced analysis.

5.1 Summary

The data received consisted of the daily catch and pot lifts for the fishing seasons from 1993/94 to 1997/98 for the three main fishing zones in Western Australia. From this, 1 pull values only were chosen to cater for the need of the time series to be sequential in time. Although the raw data came in five water depths this was condensed into two separate water depths, that for the purpose of this study were called shallow water and deep water. The data was then converted into catch rates, which would be used for the analysis. The western rock lobster data also came from the three main fishing zones in Western Australia, Zone A, Zone B and Zone C. Problems were encountered with Zone A because it had a shorter season than the other two zones with only 4 months of fishing. This short season resulted in four 30-day cycles that were shortened to only two or three cycles when the centered moving average method was used. It was felt that this number of cycles was not really adequate for reliable results. Calculations were still made with the data for Zone A, however, we must be careful when drawing conclusions for this zone.

For this thesis daily data was used and some decisions had to be made so that the most reliable data was used. The data is collected from the fishers and due to environmental and social factors not all boats fished on all days and numbers of pots lifted also varied from day to day. Data that were considered not reliable at either the beginning or the end of the fishing season were discarded. For non-fishing days that resulted in missing data (mainly found in the deep-water data) a simple averaging technique was used, mainly due to the large amount of data we were trying to process. Other methods have been used. Vance and Staples (1992) transformed catch data that contained large numbers of zeros as $\log_{10}(\text{catch} + 0.1)$ to satisfy the assumptions of normality. Staples and Vance (1985) found that for short time scales square root transformations were sufficient to stabilise variances but for longer time series, fourth root transformations were often necessary. This may have an effect on the results if the missing data coincided with the full moon phase.

We next looked at identifying the trend so that it could be removed from the data in order that the cyclic component of the series could be analysed. A thirty point centered moving average method and a curve fitting method were used to identify the trend. We also did a spectral analysis in order to understand the data better. The spectral analysis confirmed the presence of a strong cyclic component in the data.

Once the trend was removed we then used the Decomposition method in *Minitab* and the Holt-Winters (Winters) method to isolate the cyclic component from the series.

The cyclic indices calculated were then compared to the moon phase. The index corresponding to the full moon was taken to be the lowest value within the time frame of actual full moon date ± three days. Averaging was not considered feasible because it was found that there was a steep increase in indices almost immediately after this lowest point was achieved in most of the series. It was felt that if averaged this would not accurately represent the results. The indices corresponding to the other phases of the moon were those corresponding to the actual date that the lunar phase appeared during the month.

Early on in the analysis it appeared that there were two sections to the time series. Looking at the time series plots we can see the initial high catch rates followed by a severe decline, then for the remainder of the season there is a more even spread of catch rates. Therefore, it was decided to separate the fishing season into two separate parts that were simply named 'early' and 'late'. The Winters methods was used on this data so that as much data as possible available could be used. The results confirmed that the earlier and later sections of the season gave significantly different results often enhancing the cyclic component.

5.2 Comparisons

Firstly we may want to compare the three methods used. We can compare the cyclic indices calculated that correspond to the full moon phase. As we might expect the results from the Decomposition, CMA and Polynomial methods were similar since their estimations of trend were very similar. However, there is some variation shown in Zone B for deep water. The Winters method calculated cyclic indices similar to the Decomposition method with little variation seen for the full moon phase. Zone B and C, shallow water and Zone C deep water all yield very similar results for the three methods. All three methods yielded indices corresponding to the full moon that were lower than 1 for all zones over all seasons and depths.

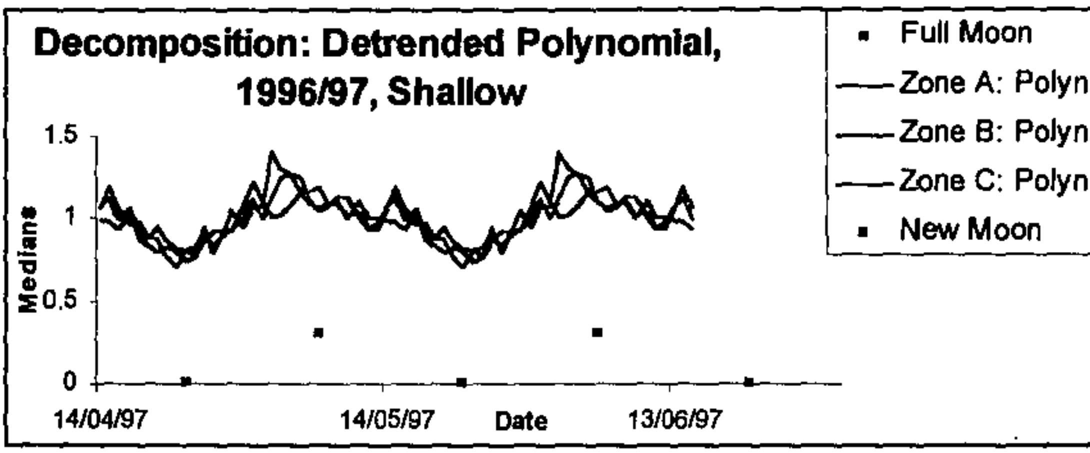


Figure 5.1 Comparing the three zones using the Winters methods .

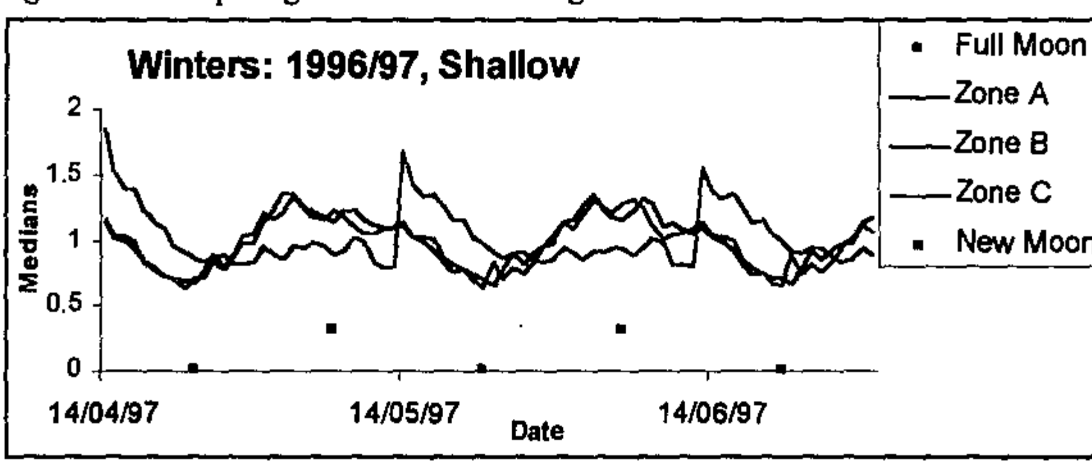


Figure 5.2 Comparing the three zones using the Decomposition method with the CMA series.

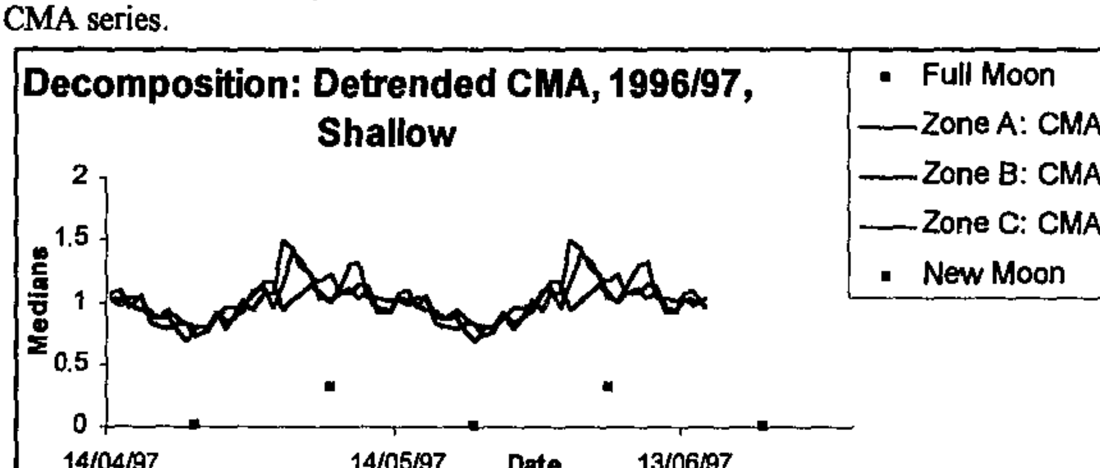


Figure 5.3 Comparing the three zones using the Decomposition method with the polynomial series.

Figures 5.1, 5.2 and 5.3 compare the zones and methods used for the shallow water. Zones B and C show similar trends which we found to be a fairly consistent representation of all the years for the shallow water. Zone A appears to be slightly different than Zone B and C using the decomposition method. With the Winters method Zone A appears quite different, though we are not sure of the cause. However, we can still discern that significant lower indices are found during the full moon phase. Overall the shallow water was found to have a more stable cyclic component that was fairly similar from year to year and zone to zone.

Comparing the two water depths, shallow and deep, (that is 0–20 fathoms and 20–50 fathoms respectively), when compared to the full moon phase, the deep water showed more variation over the fishing seasons than did the shallow water. In fact when we look at the graphs of the cyclic indices for the whole season the data for the deep water was often far more variable than the indices for shallow water (Appendix C).

Figures 5.4 and 5.5 illustrate how the indices that coincided with the full moon phase differed when we separated the season into 'early' and 'late'. For this process the Winters method was used and again we have taken the lowest value within the seven-day full moon phase period. Shallow water for both Zone B and C exhibit little difference between the results of the total season data and the 'late' data. However, as seen in Figure 5.4 the 'early' series deviates significantly from the other two except for the season 1996/97 for Zone C and 1994/95 Zone B, shallow water (Appendix D).

Looking at Figure 5.5 we see that for the deep-water there is a lot of deviation between the three series with perhaps the least amount of variation for the 1997/98 season. From these results we could ascertain that there is merit in looking at the western rock lobster data as two separate series for each fishing season. However, we can see that all of the indices corresponding to the full moon phase are well below one, indicating a reduction in comparison to the rest of the season.

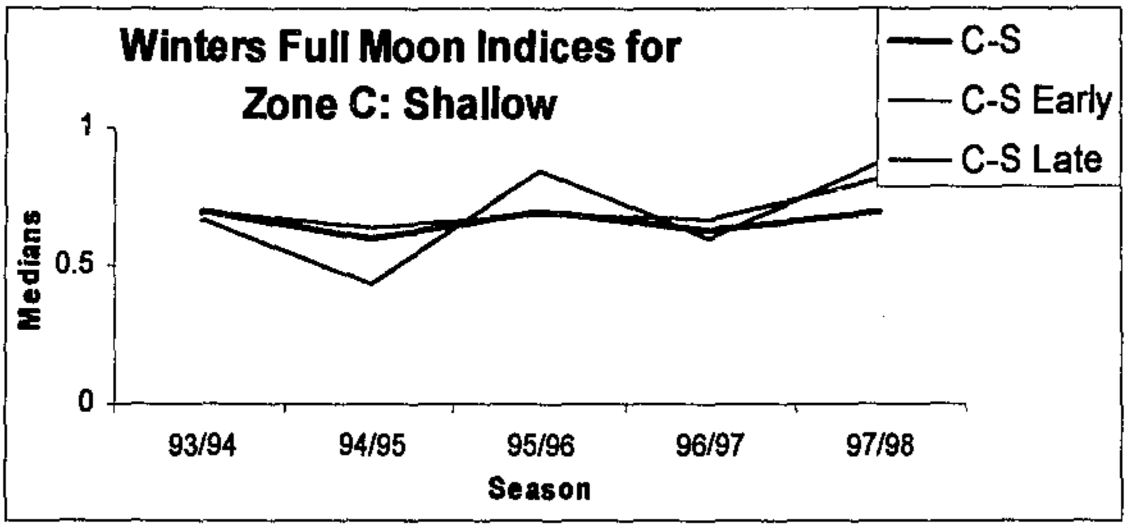


Figure 5.4 Shows the different results when the season is separated into two sections for Zone C, shallow-water over all seasons.

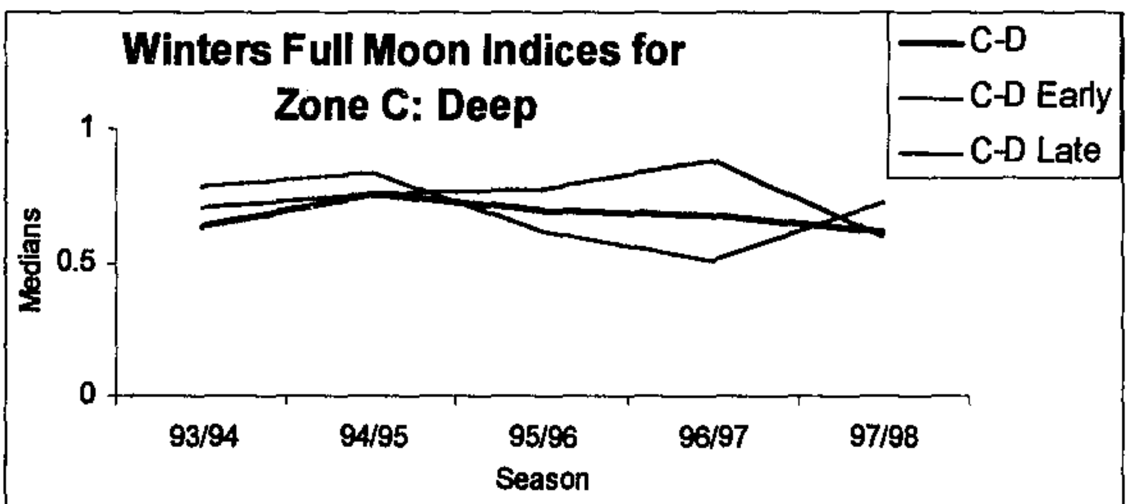


Figure 5.5 Shows the different results when the season is separated into two sections for Zone C, deep-water over all seasons.

5.3 Future Research Directions

Although we have looked at only one variable that may be a factor in the catch rates of the western rock lobster our research indicates that a significant amount of variation in the data can be attributed to the full moon phase. As for the other phases of the moon we were unable to make any conclusions.

We have made a number of assumptions and these could be refined further. Firstly we divided the data into 0-20 fathoms and 30–50 fathoms although catch rates for five different depths are available. Our research has shown that there is a significant difference between the two depths we have chosen. Different results may be achieved if all five depths were to be analysed. Also the date chosen to separate the season into 'early' and 'late' could be chosen less arbitrarily and perhaps each season would require a different date depending on lunar phase or some other environmental factor.

Other models could be considered such as the Box-Jenkins seasonal (SARIMA) model, which is a general multiplicative seasonal integrated autoregressive moving-average model. However, for each series analysed a different set of parameters would need to be estimated. Lastly it would be beneficial to incorporate these results with studies that incorporate other environmental and even biological factors, particularly tides, water temperature and swells.

5.4 Conclusion

This thesis has examined one environmental factor, the moon phase, with special focus on the effects of the full moon. There are many environmental factors that affect both fishers and lobsters, such as swells, water temperature and tides. These may all play a role in the lobster catch rates. The catch rates for deep water were found to be much more erratic and it is suspected that other factors are involved which would explain this irregular behaviour.

However, the processes we have used show clearly that the presence of the full moon has a significant effect on the catch rates of the western rock lobster. These results indicate that full moon phase may need to be taken into account when models are being used to asses catch rates and that their inclusion will provide a better picture of the fishery and thereby produce more accurate and informed results.

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Appendix A

Full Moon Indices:

The index shown is the lowest value + or - 3days from the actual moon date.

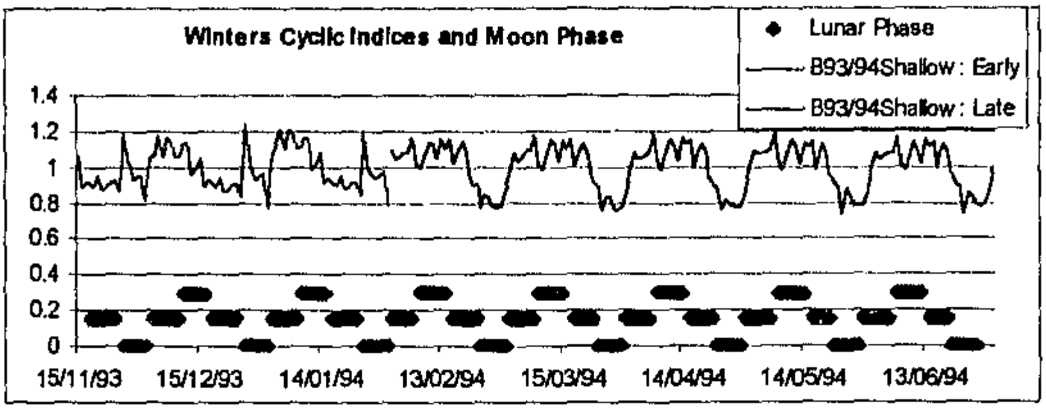
	CMA - SHALLOW				**CMA - DEEP**		
Zone	A	B	C		A	B	C
93/94	0.71873	0.73666	0.62057		0.63158	0.81175	0.60024
94/95	0.74515	0.6153	0.6337		0.76246	0.63106	0.57853
95/96	0.8466	0.7665	0.61974		0.89112	0.63484	0.72137
96/97	0.77705	0.72921	0.6937		0.7763	0.65358	0.75343
97/98	0.75306	0.7098	0.7433		0.69509	0.86956	0.77775

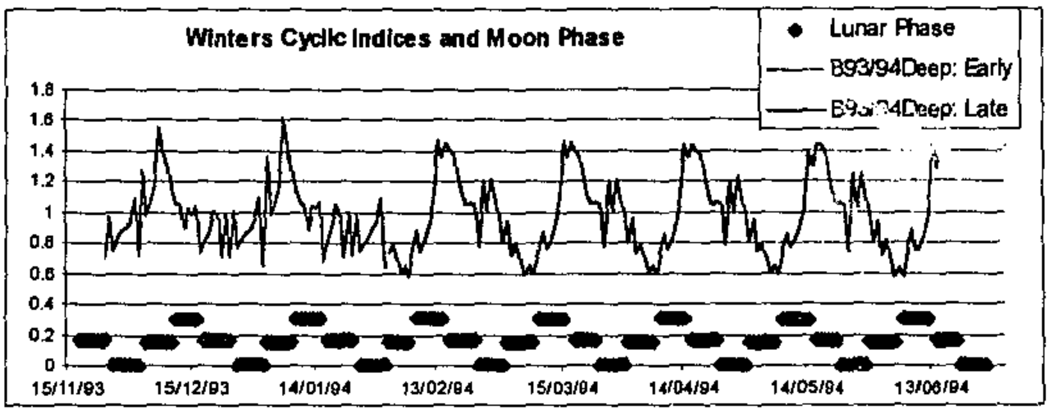
	Polynomial – SHALLOW				**Polynomial - DEEP**		
Zone	A	B	C		A	B	C
93/94	0.70702	0.7487	0.63899		0.65605	0.68667	0.65487
94/95	0.83287	0.7226	0.64711		0.77877	0.63575	0.59342
95/96	0.82713	0.72495	0.61941		0.9094	0.63484	0.76412
96/97	0.77115	0.73188	0.71128		0.78454	0.74269	0.71524
97/98	0.78497	0.77095	0.77644		0.7288	0.70317	0.69206

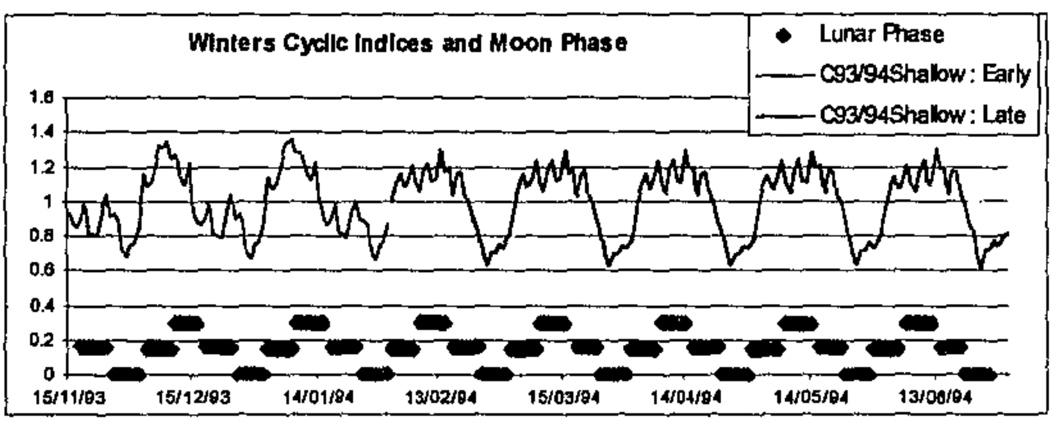
	Winters - Shallow				**Winters - Deep**		
Season	A	B	C		A	B	C
93/94	0.70229	0.79378	0.69465		0.7631	0.87281	0.63635
94/95	0.77428	0.64619	0.60046		0.83783	0.7104	0.75079
95/96	0.7371	0.73603	0.69656		0.74248	0.67099	0.69324
96/97	0.84556	0.68472	0.63129		0.81771	0.53653	0.66994
97/98	0.63377	0.79799	0.70093		0.65645	0.79963	0.61206

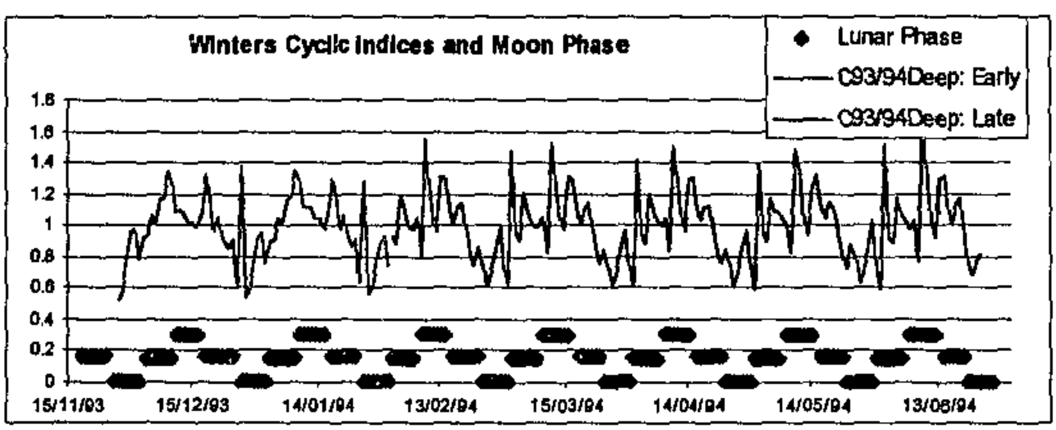
Appendix B

Winters Cyclic Indices – 'Early' and 'Late' compared to Full Moon Phase.

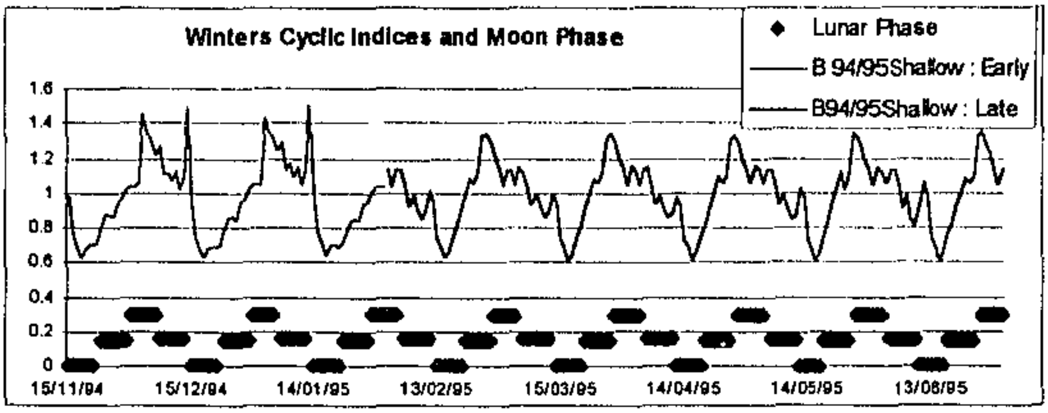


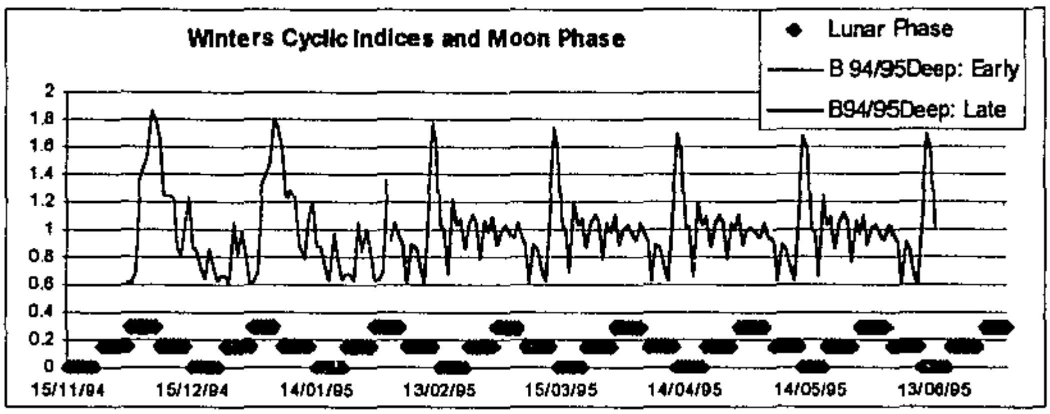


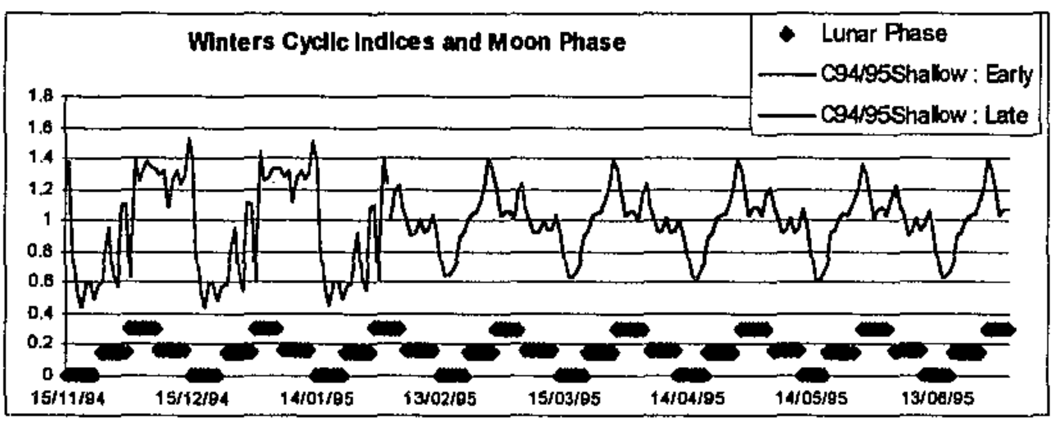


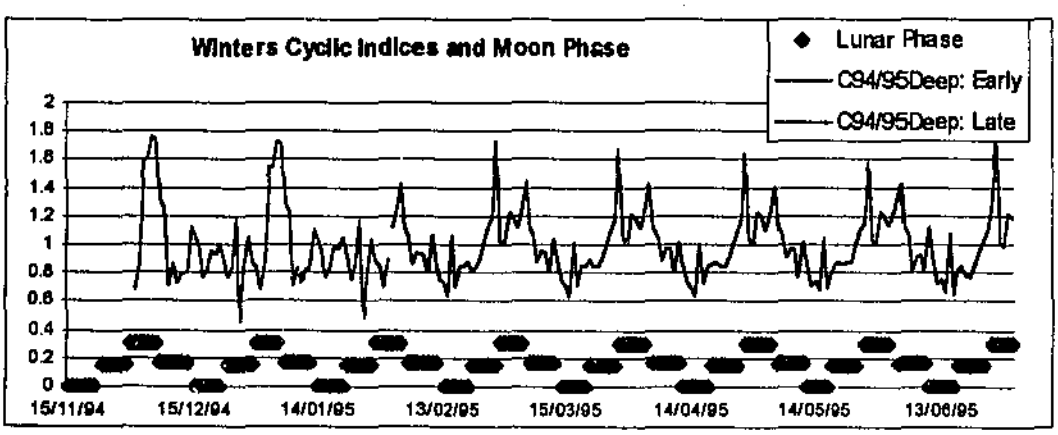


Winters Cyclic Indices – 'Early' and 'Late' compared to Full Moon Phase, continued.









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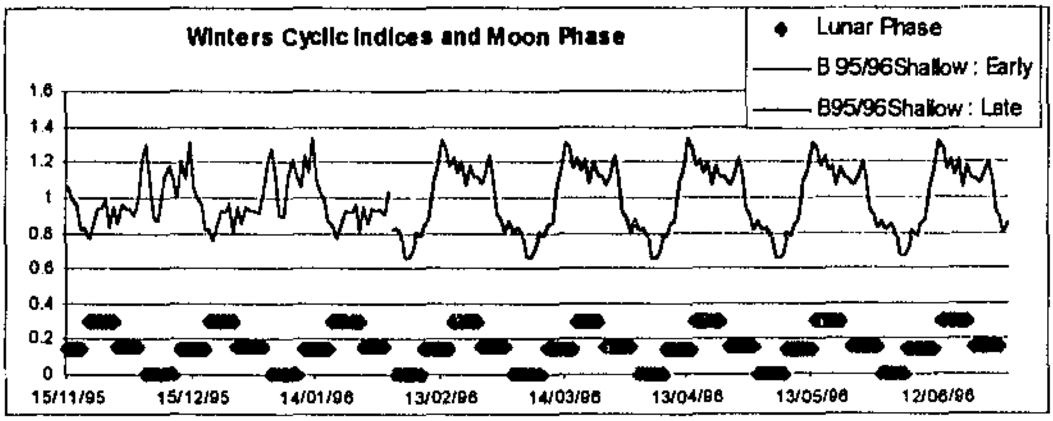
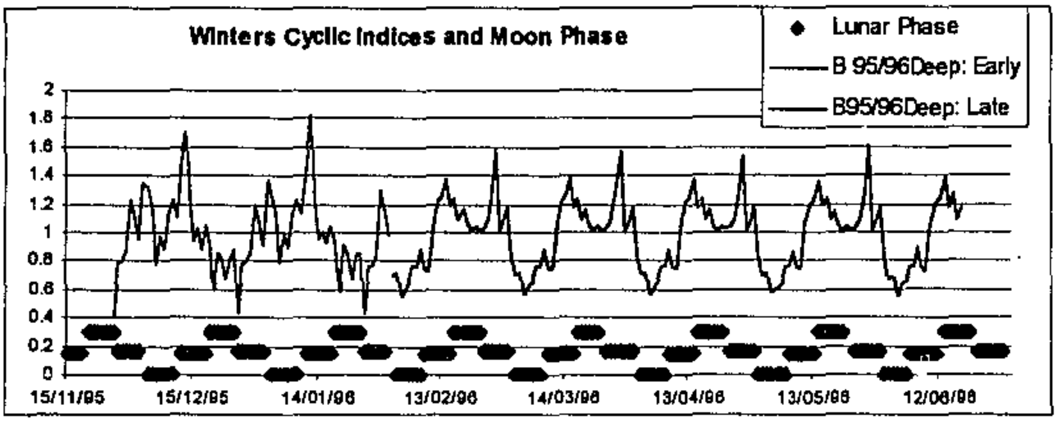
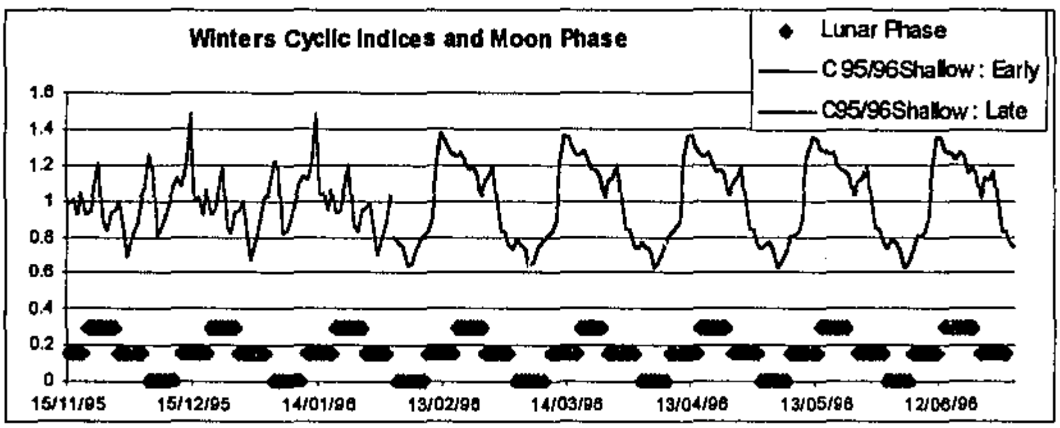
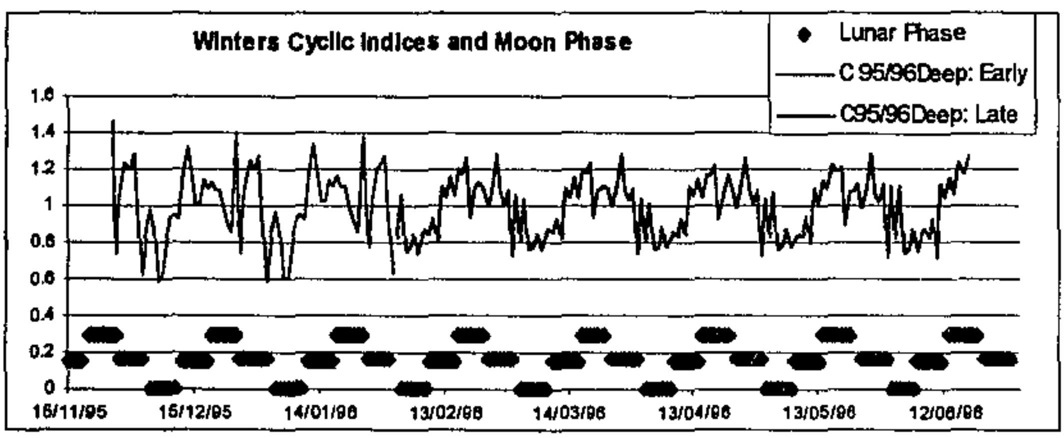
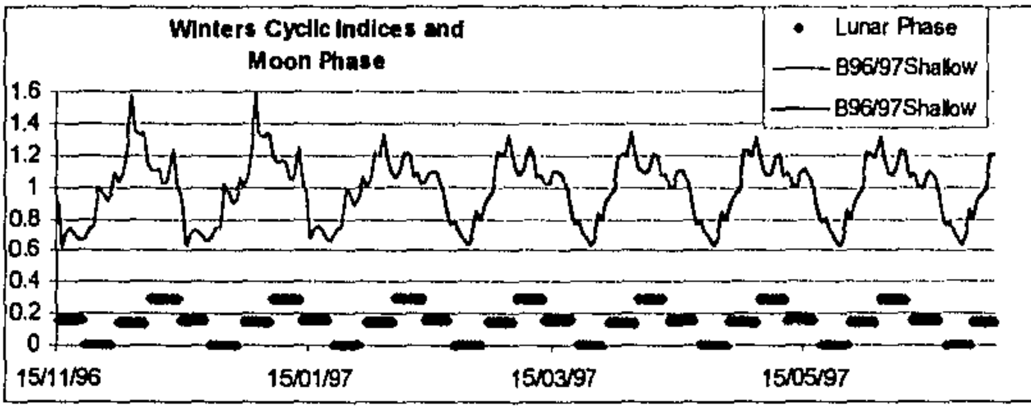


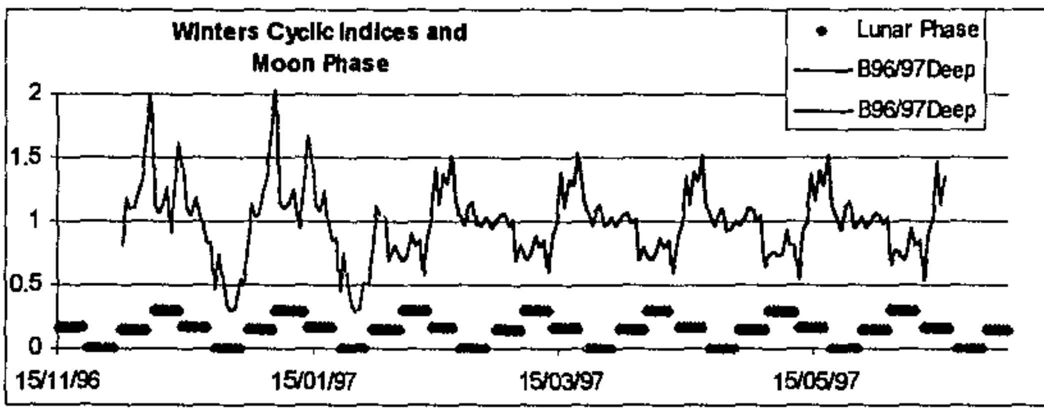


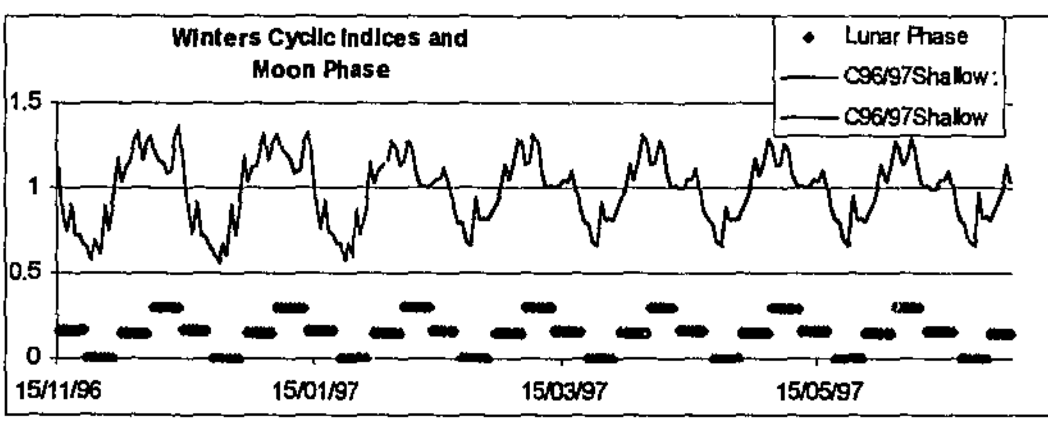


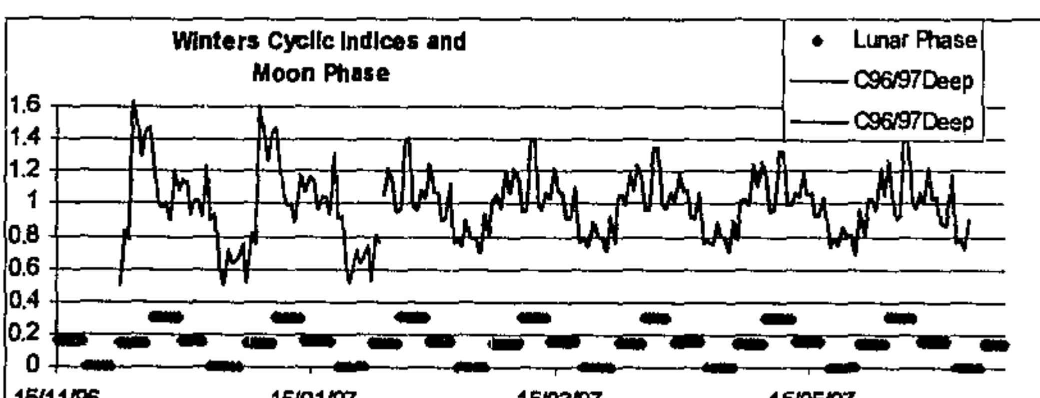


Winters Cyclic Indices – 'Early' and 'Late' compared to Full Moon Phase, continued.



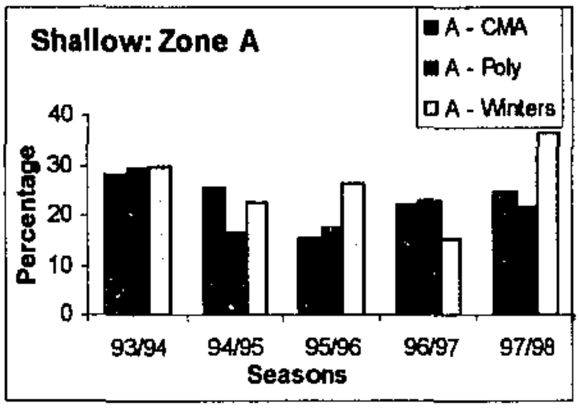


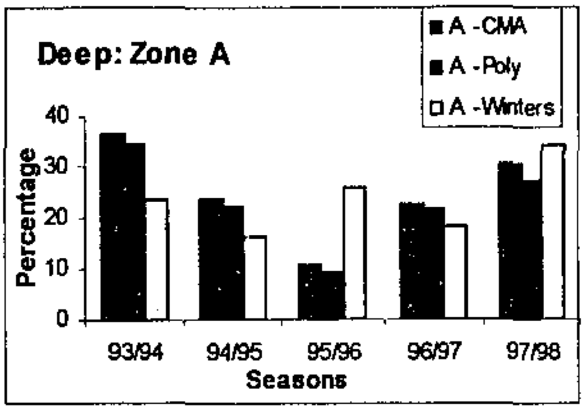


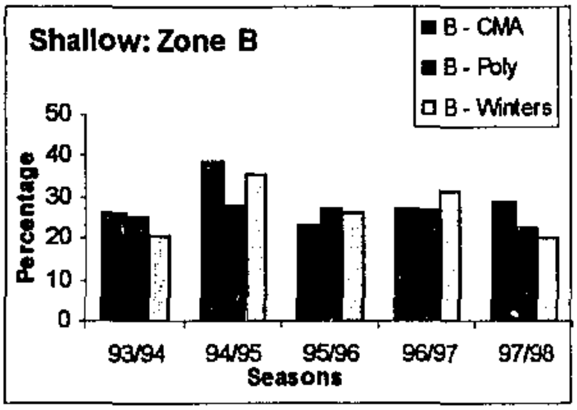


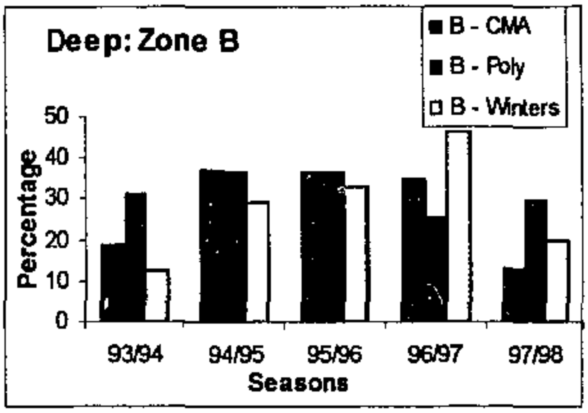
Appendix C

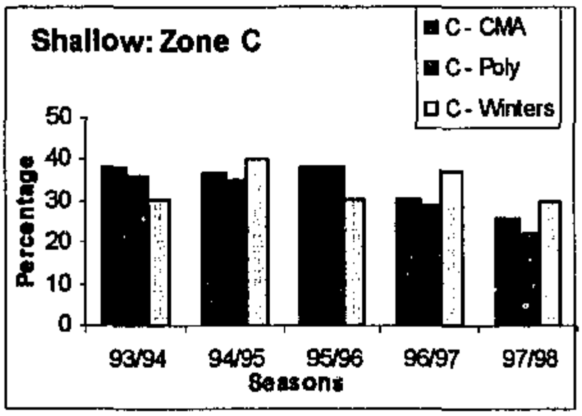
The cyclic indices that coincide with the full moon quarter calculated by the three methods have been compared by the following graphs. Comparisons were made over five years for the three major fishing zones in Western Australia. The lowest index in the full moon quarter is given. The percentage is simply the difference between the index and the mean (equal to one) that is shown as a percentage.

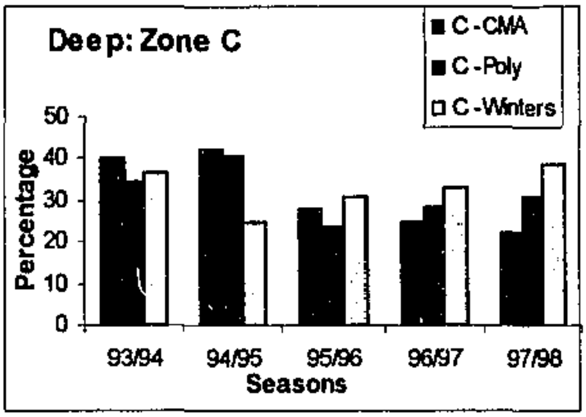






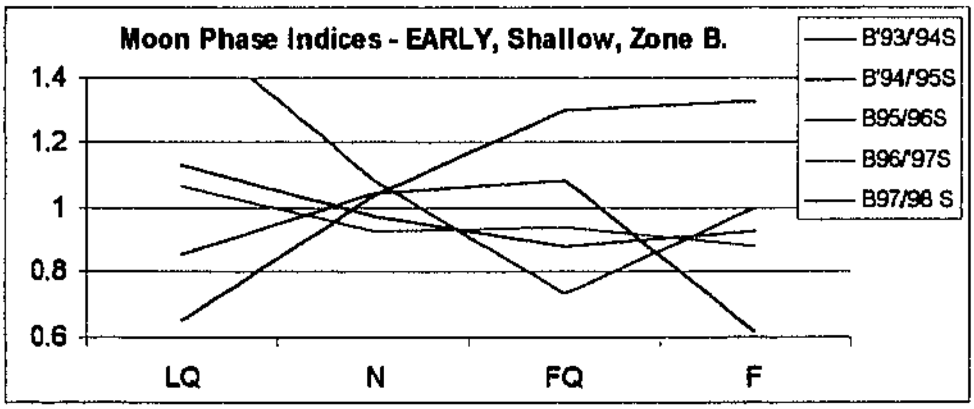


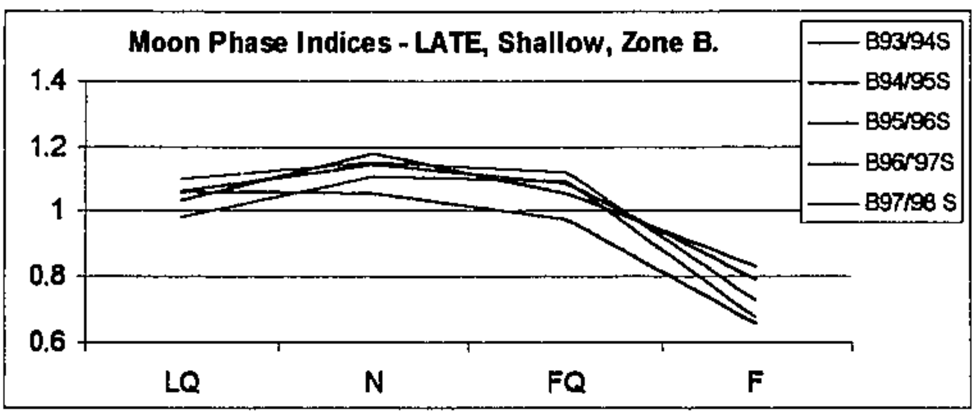


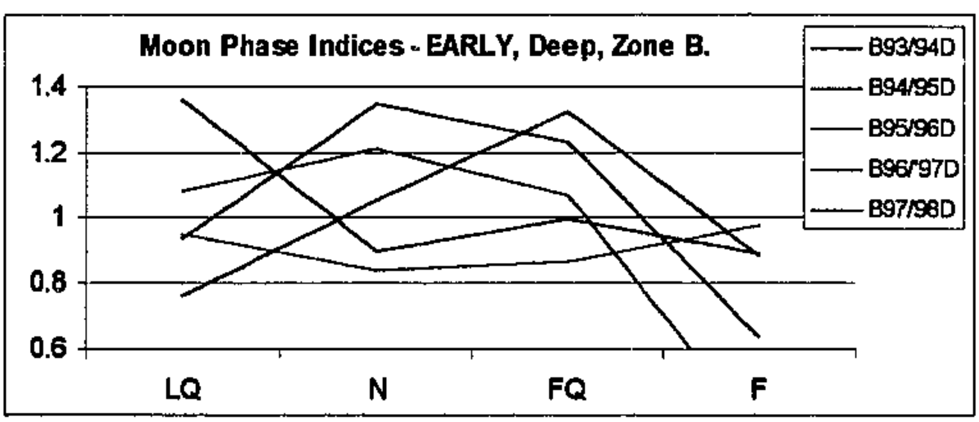


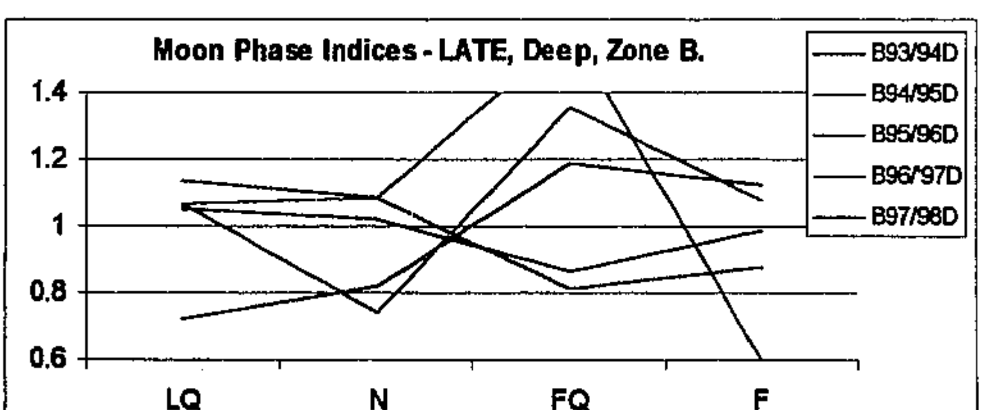
Appendix D

Winters method: 'Early' and 'Late' results. Cyclic indices coinciding with the four phases of the moon. Where LQ is the last quarter, N is the new moon, FQ is the first quarter and F is the full moon.

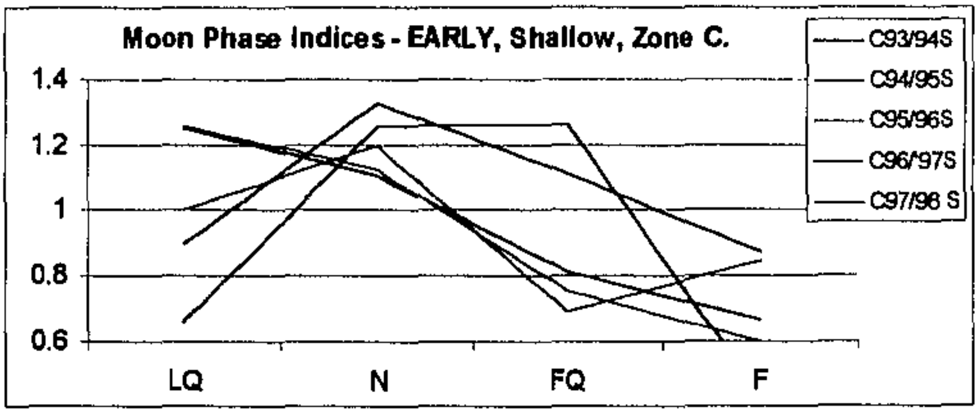


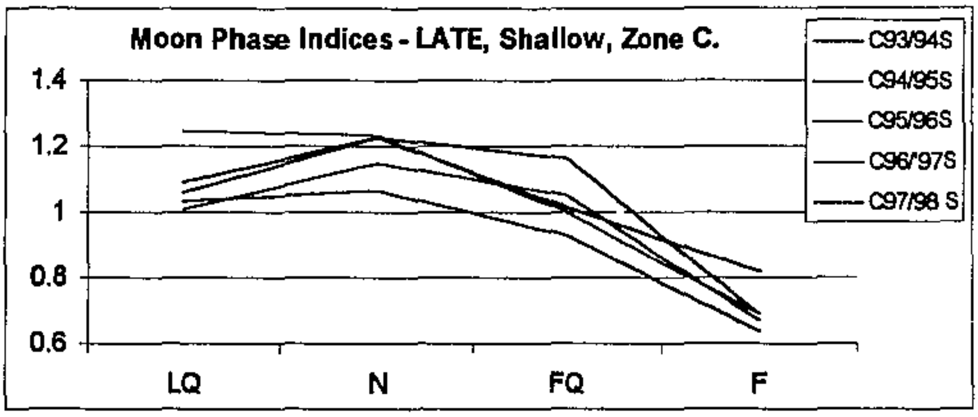


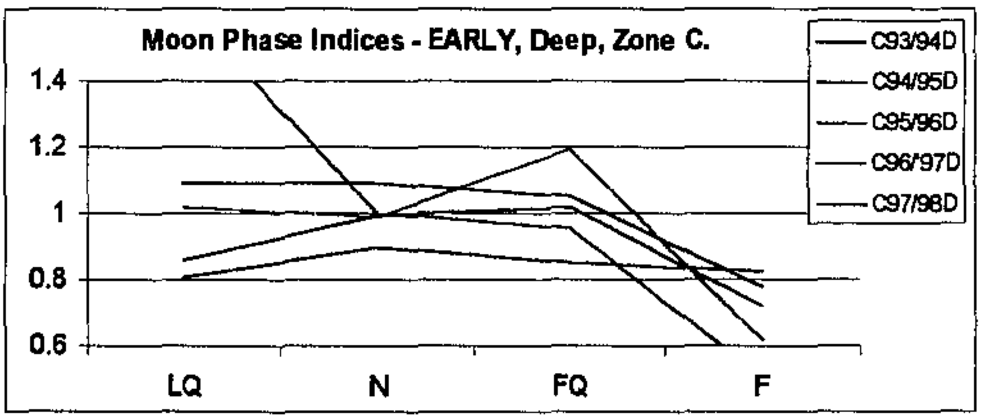


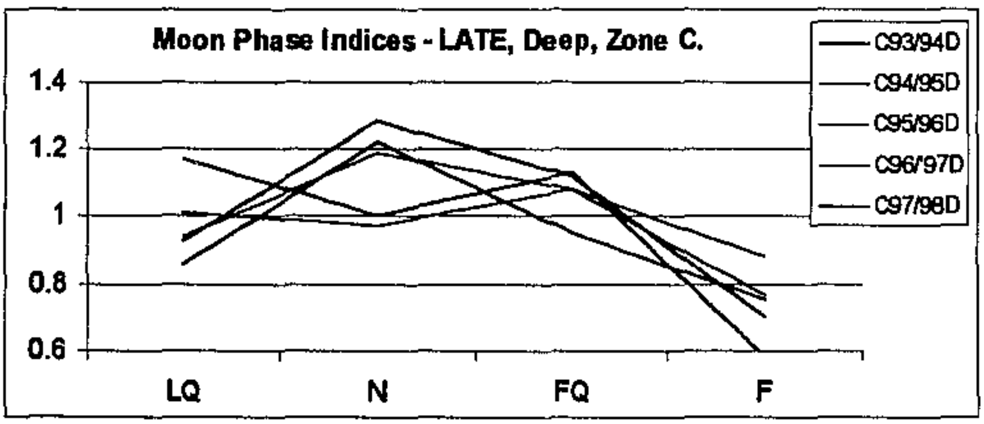


Winters method: 'Early' and 'Late' results. Cyclic indices coinciding with the four phases of the moon. Where LQ is the last quarter, N is the new moon, FQ is the first quarter and F is the full moon, continued.



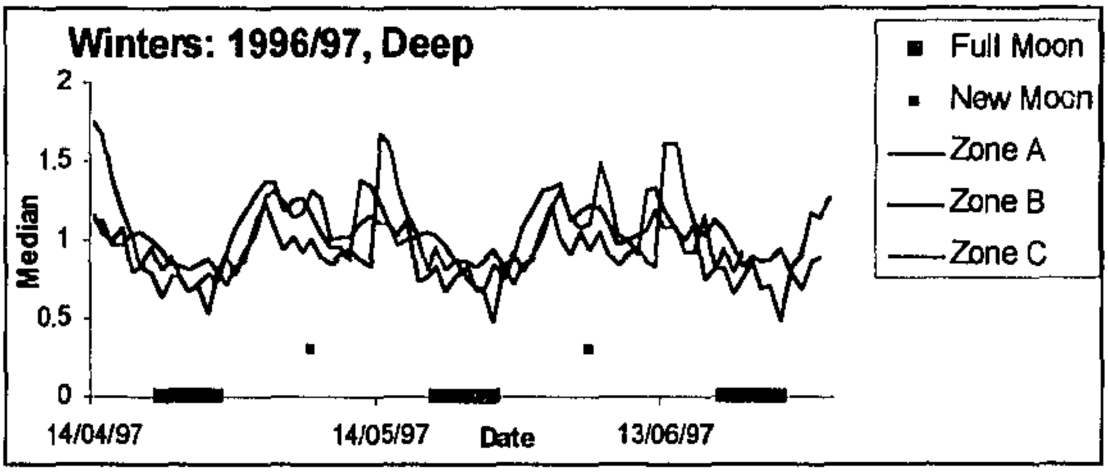


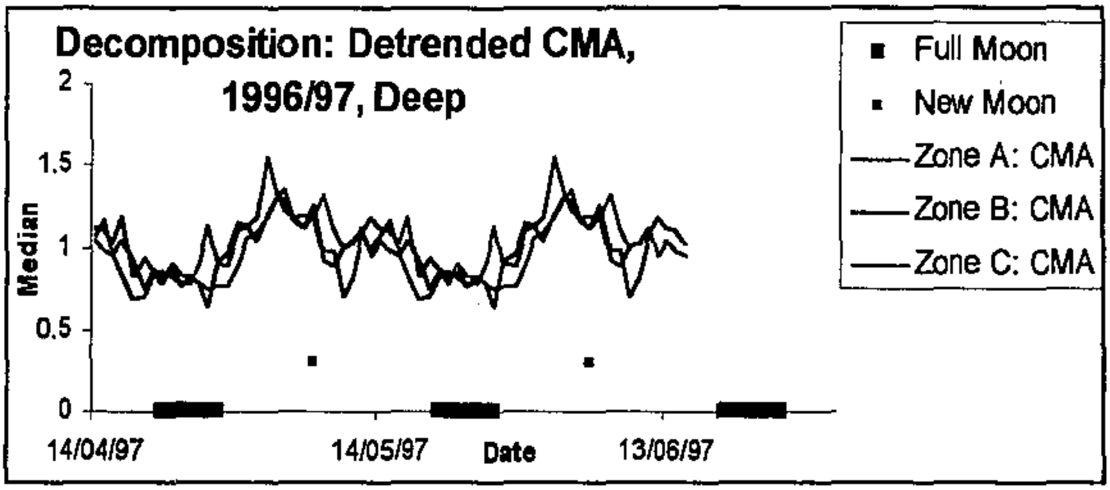


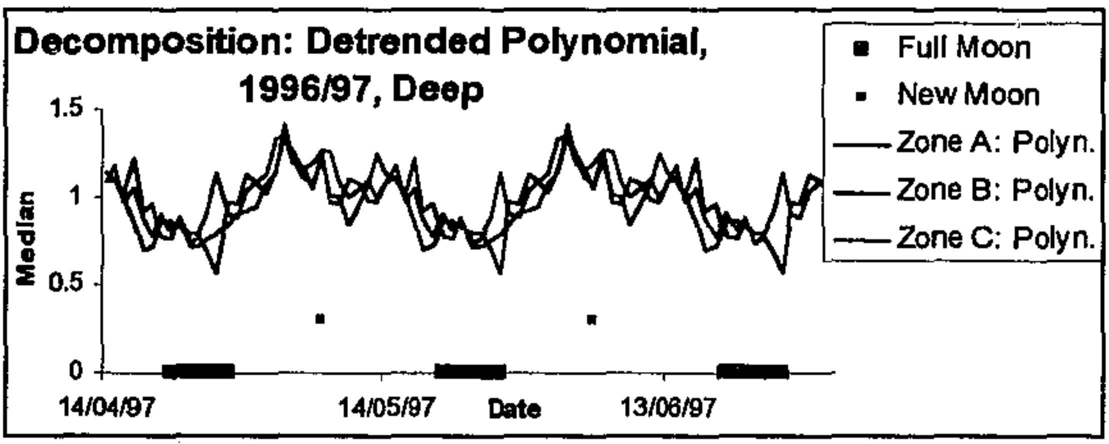


Appendix E

Comparisons of the three zones shown against the full moon quarter.



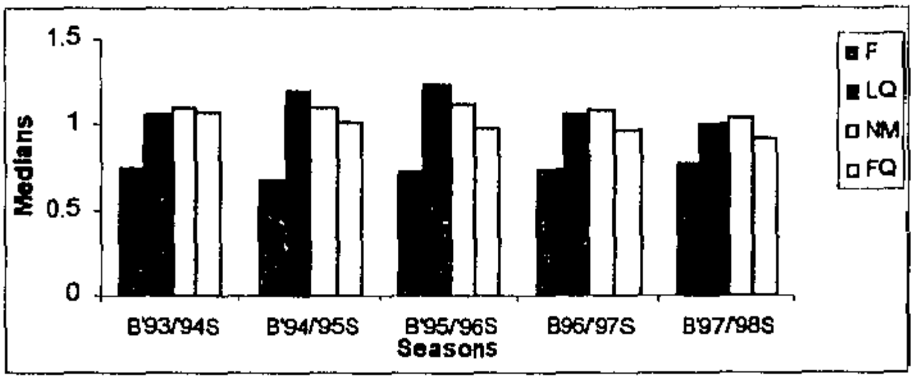




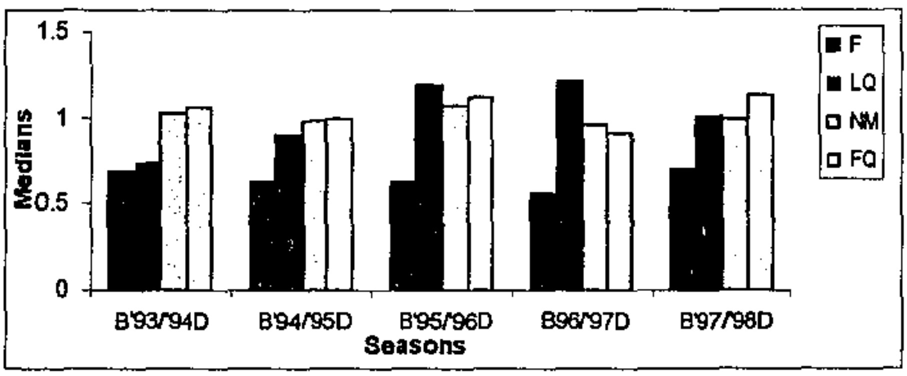
Appendix F

Cyclic Indices calculated for the four moon phases using the Decomposition method on the detrended polynomial series.

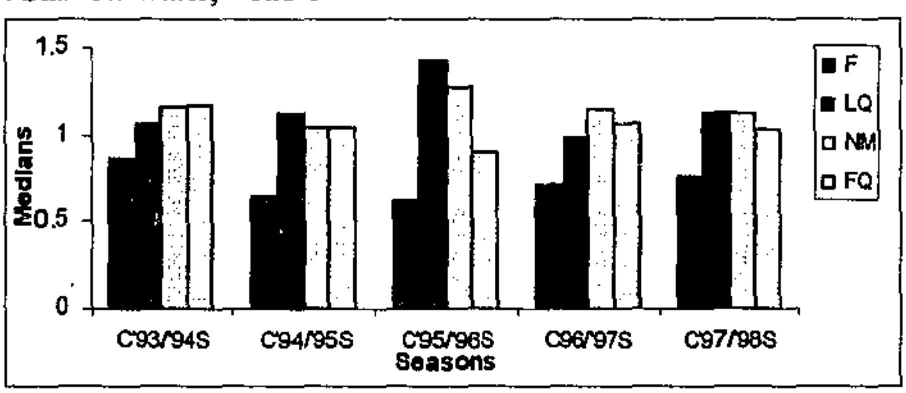
1. Shallow water, Zone B



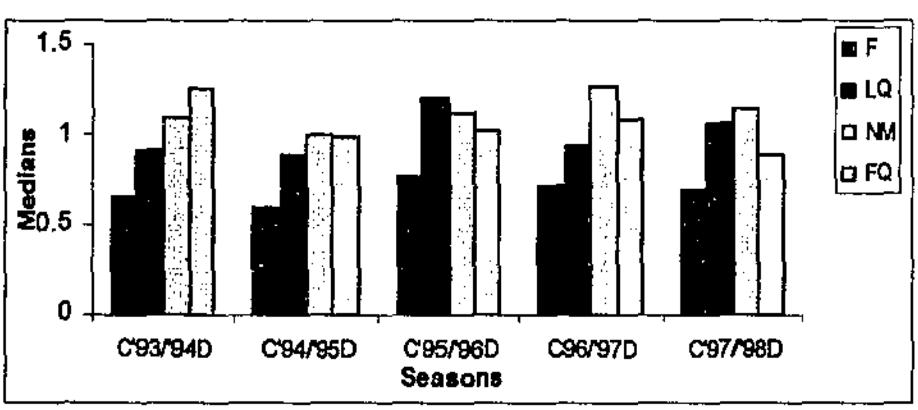
2. Deep water, Zone B



3. Shallow water, Zone C

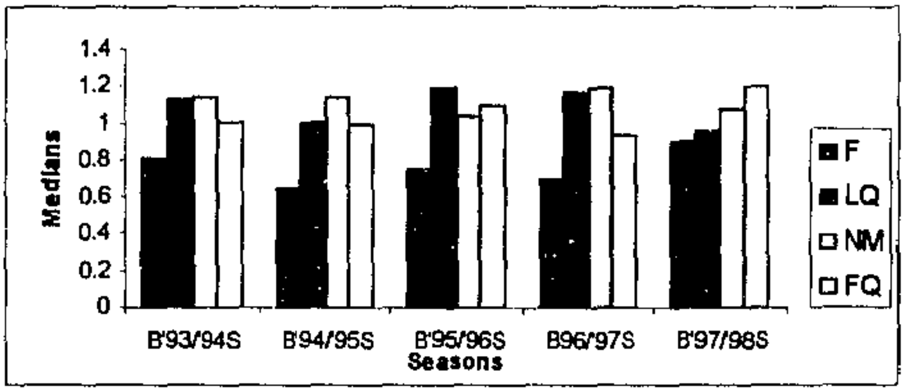


4. Deep water, Zone C

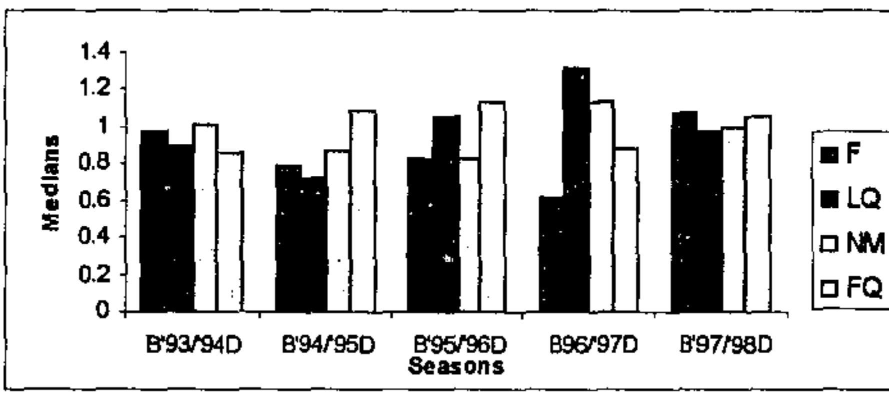


Cyclic Indices calculated for the four moon phases using the Decomposition method on the Winters method.

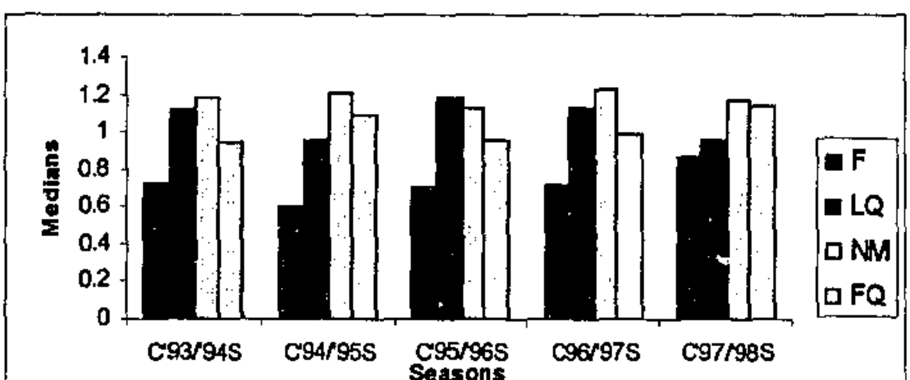
5. Shallow water, Zone B



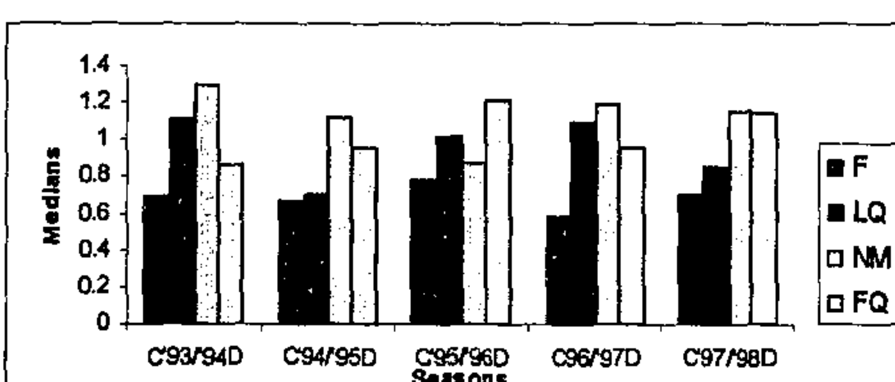
6. Deep water, Zone B



7. Shallow water, Zone C

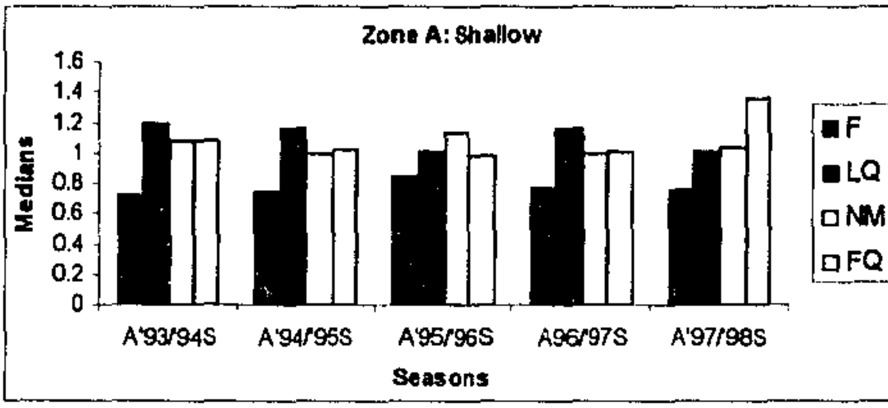


8. Deep water, Zone C

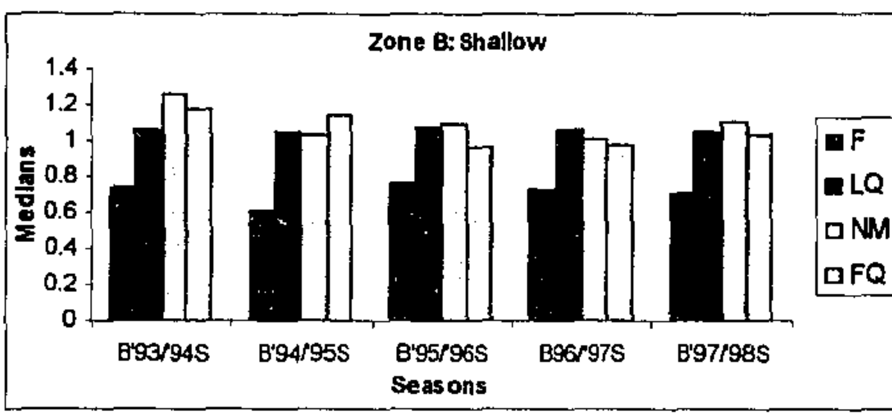


Cyclic Indices calculated for the four moon phases using the Decomposition method on the detrended CMA series.

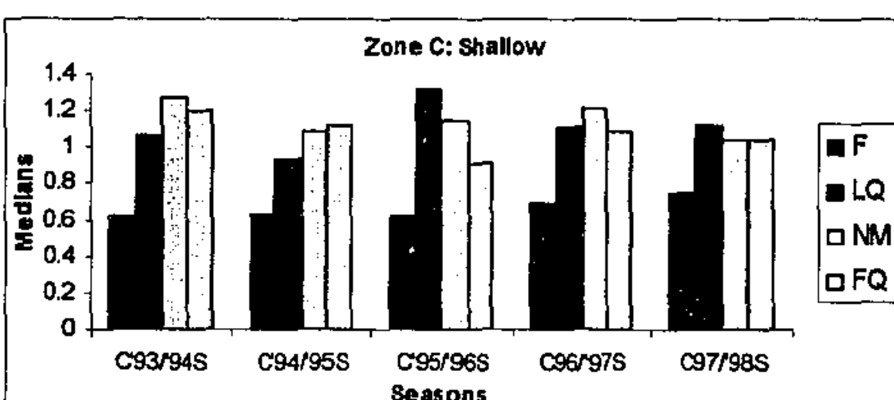
9. Shallow water, Zone A



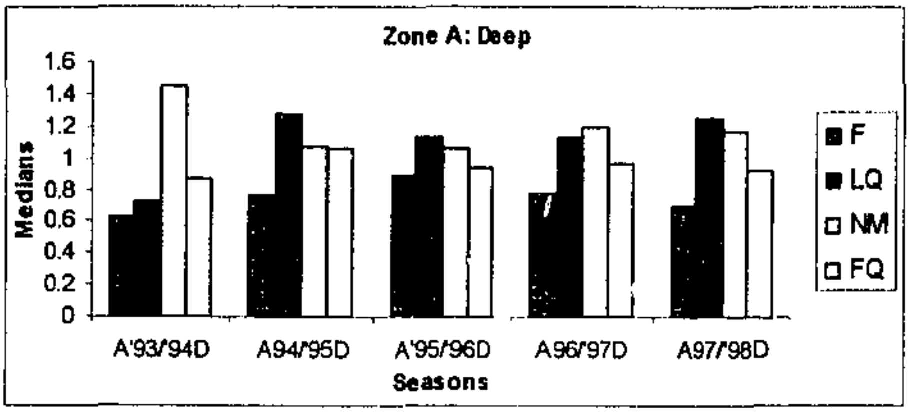
10. Shallow water, Zone B



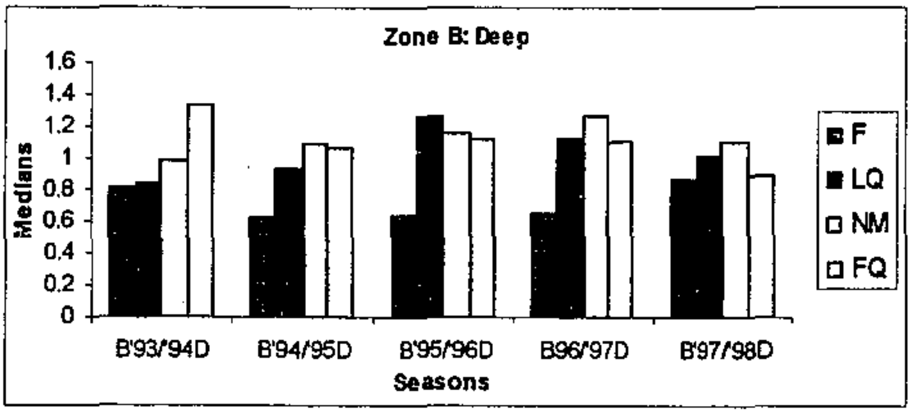
11. Shallow water, Zone C



12. Deep water, Zone A



13. Deep water, Zone B



14. Deep water, Zone C